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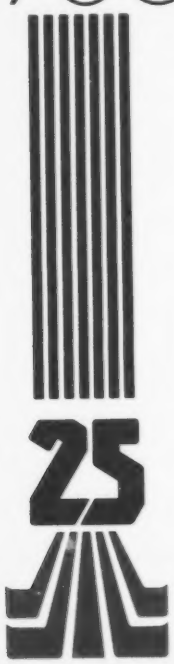

ANNIVERSARY REPORT

NASA
National Aeronautics and
Space Administration

Marshall Space Flight Center

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PREFACE

The Marshall Space Flight Center marks its 25th anniversary with a record of notable achievements:

- Launch vehicle for the free world's first manned spacecraft
- World's largest launch vehicles
- Launch vehicles that sent man to the moon
- World's only manned lunar surface vehicle
- Free world's first space station
- Nation's largest orbital observatories
- First materials processing experiments in space
- Propulsion systems for world's first Space Shuttle
- First commercial product made in space.

These accomplishments are the essence of the Marshall Center's history. Behind the scenes of our space launches and missions, however, lies a story of challenges faced and problems solved. The highlights of that story are presented in this illustrated report of our first 25 years.

This book is organized not as a straight chronology but as three parallel reviews of the Center's major assignments: propulsion systems and launch vehicles, space science research and technology, and manned space systems. Our general goals have been to reach space, to know and understand the space environment, and to inhabit and utilize space for the benefit of mankind. The text of each chapter reports on the past achievements, present activities, and future plans of the Center as an entity; the photographs show people at work, making history.

This three-part treatment of the Center's history is a convenience that enables us to trace the development of Marshall's major roles with thematic continuity. In reality, of course, there is considerable interdependence and inter-relationship throughout the Center. For example, the Apollo Telescope Mount and Skylab, discussed here in different chapters, were not two separate programs; rather, the telescope was an integral part of Skylab. Within our matrix organization, all projects benefit from the shared technical and managerial capabilities of the Center.

This report also includes a chronology of major events, presented as a fold-out chart for ready reference. At a glance, the reader can see concurrent events in each of the Marshall Center's major endeavors – space vehicles, space science, manned systems – and place them in the context of developments within the Center and the community.

We are aware that the story of Marshall Space Flight Center can be told in many voices, with different themes. Each employee has a unique perspective on the accomplishments of the past 25 years. This report speaks of the Center's achievements and challenges in general, none of which would have been possible without the specific accomplishments of dedicated individuals. On this anniversary, we celebrate their successes and encourage all to learn from Marshall's history as they remember it. We consult the past to guide our progress into the future.

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COMMITMENT TO EXCELLENCE

On this 25th anniversary of the founding of Marshall Space Flight Center, we whose careers are linked to the space program feel a nostalgia that is both communal and individual; the history of NASA and our personal lives are so intertwined as to be virtually inseparable. We have changed and matured, and so has the Center. We have grown professionally in response to the challenges of space, and we have also become a family united by shared goals and aspirations. While we reflect on the past, we are eager to proceed into the exciting future.

The George C. Marshall Space Flight Center, established by Presidential Executive Order to support a vigorous national program for the exploration of space, was officially designated on July 1, 1960. During its first quarter century, the Marshall Center has been recognized as one of the most capable, most versatile science and engineering institutions in the world. Marshall has a well-earned reputation as a developer and manager of large, complex systems as diverse as launch vehicles, satellite observatories, and manned work places in space. Marshall is NASA's leading center for propulsion systems and launch vehicles, yet we have broadened our base to include many other quite different projects. By virtue of its multidisciplinary talents and resources, the Center has been, and continues to be, a major force in the nation's space program.

The history of Marshall Space Flight Center is a chronicle of hard work and dependable hardware. Our products – the giant Saturn launch vehicles, Skylab, the Space Shuttle propulsion systems, Spacelab, Space Telescope, the many scientific spacecraft and payloads – are tremendous achievements. Our people are true pioneers, visionary leaders who extend the limits of technology and boldly advance into the new frontier of space.

The motivating force of Marshall Space Flight Center is a commitment to excellence, manifested in the work of its people. One success after another – 2 Mercury-Redstone launches, 32 Saturn launches including 9 lunar missions, 3 Skylab missions, 3 High Energy Astronomy Observatories, some 20 Space Shuttle launches, 3 Spacelab missions, a remarkable new Space Telescope to be launched in 1986, and a host of other achievements – testify to the highest standards of performance in our day-to-day business. The Marshall Center is a disciplined organization dedicated to the common goal of a successful space program for the benefit of mankind.

Because our people adhere tenaciously to the standard of excellence, despite often severe time and budgetary pressures, the history of the past 25 years is a sterling record of success. Now we are poised at the threshold of another great endeavor that will challenge us far into the future – the establishment of a permanent presence in space in an inhabited Space Station. What we do today and what we are capable of achieving tomorrow depend on our continued, unstinting commitment to excellence in thought and deed, in theory and practice.

We have certain traditions at Marshall: professionalism and quality in all disciplines, effective management, teamwork, pioneering scientific research, and advancing technology. This heritage continues in our work today, and it must remain vital in our future efforts. Our history is not a closed book; it inspires and guides us.

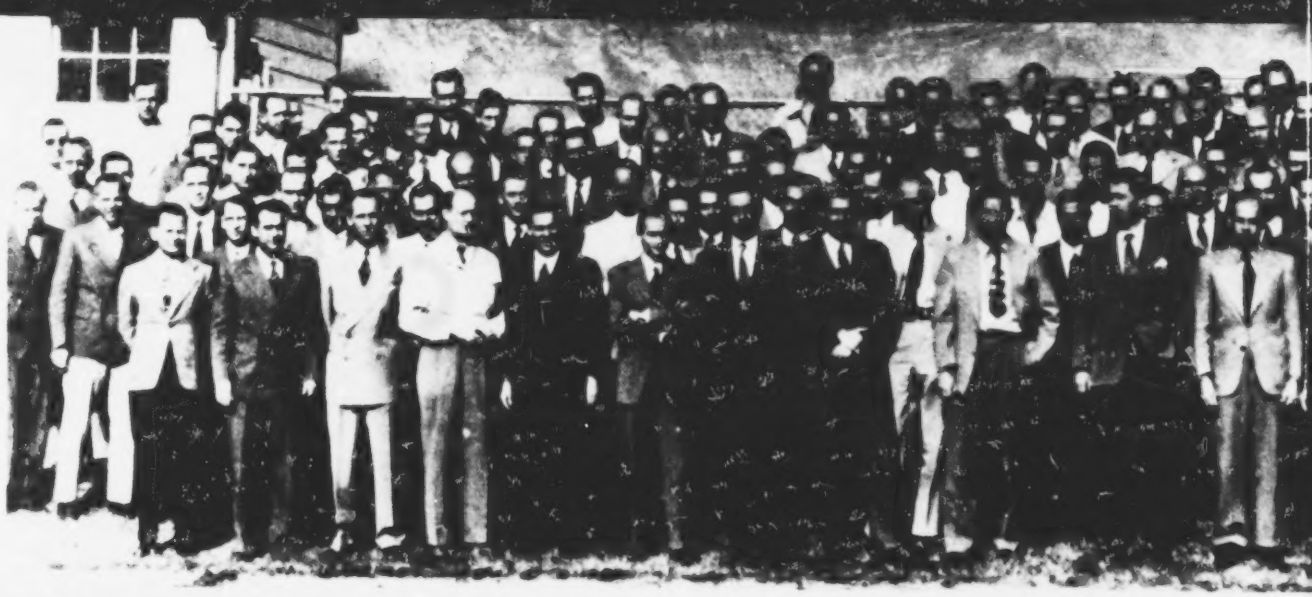
As I look back to the origins of Marshall Space Flight Center, our history appears in the blinding light of rockets and launch vehicles. Looking ahead, I see a future equally bright with challenges that will tax our ingenuity and demand our best efforts. As always, we will succeed if in our daily work we honor our commitment to the standard of excellence.

That is the Marshall tradition; may it remain so.

W. R. Lucas

W. R. Lucas, Director
George C. Marshall Space Flight Center
July 1985

A UNIQUE NATIONAL RESO



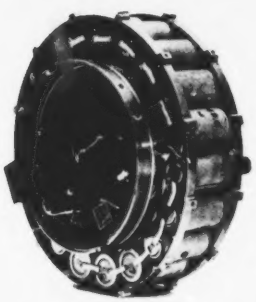
German rocket experts in Fort Bliss before moving to Huntsville

Alabama Space and Rocket Center Archives photo

In the blockhouse at Cape Canaveral awaiting launch of Pioneer 4 (1959)

The United States' first satellite, Explorer 1

Pioneer 4 probe, first U.S. satellite to orbit the sun, launched in 1959



URCE:

"At Huntsville we have one of the most capable groups of space technicians in the country," a government official told Congress in 1959. "I think that it is a unique group ... a national resource of tremendous importance."

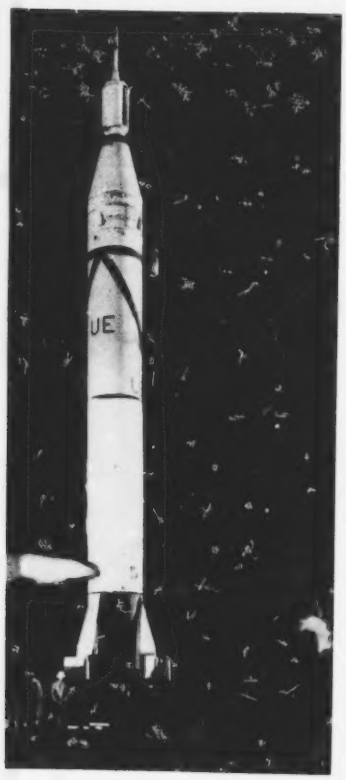
Alabama Space and Rocket Center Archives photo

Years before either the National Aeronautics and Space Administration (NASA) or Marshall Space Flight Center (MSFC) was established, a group of scientists and engineers known as the von Braun rocket team became prominent in America's fledgling space program. Dr. Wernher von Braun and 118 German rocketry experts and their families came to the United States in the mid-1940's. Initially employed by the Government at Fort Bliss, Texas, the group moved to Huntsville in 1950. Here the Army's Redstone Arsenal offered an excellent site for basic rocket research and guided missile development.

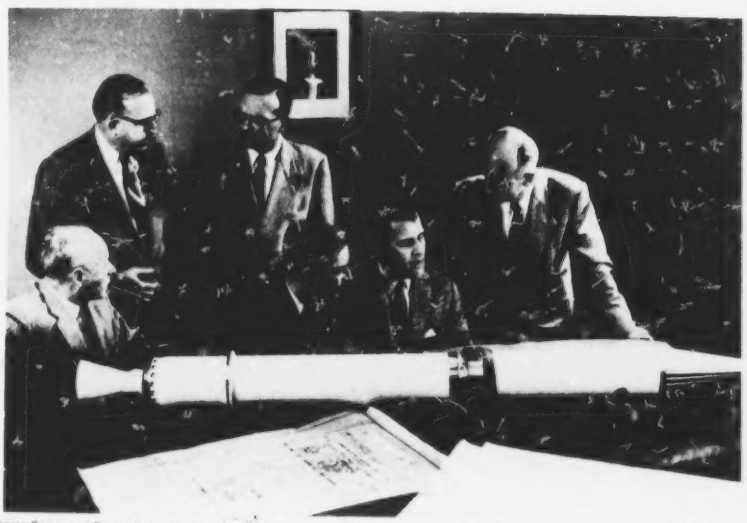
During the 1950's, this team was expanded by nation-wide recruitment of scientists and engineers, and it became the core of the Army's Guided Missile Development Group. The group initiated research and development of the 75,000 pound thrust Redstone guided missile, first launched in 1953, and started the larger Jupiter missile program in 1955. The next year, the Army Ballistic Missile Agency (ABMA), which incorporated this resident technical cadre in key positions, was established at Redstone Arsenal. Dr. von Braun became head of the ABMA Development Operations Division.

During this period of rapid change, the momentum toward space flight increased. As head of various missile development activities in Huntsville, Dr. von Braun played an influential role in the formulation of national space policy. Among the many issues debated by advisory committees to the Government was the matter of military and civilian uses of space. Although affiliated with a military

"I consider the exploration of space and the extension of human activities beyond the confines of our planet as the supreme challenge of the age in which we live."
Dr. Wernher von Braun, 1957



Explorer 1 ready for launch atop Jupiter C rocket (1958)



Explorer project leaders: Dr. Rees, Major Gen. Medaris, Dr. von Braun, Dr. Stuhlinger and (behind) Mr. Mrazek and Dr. Haeussermann

Alabama Space and Rocket Center Archives photo

A UNIQUE NATIONAL RESOURCE

U.S. Army, Redstone Arsenal photo

ABMA laboratory directors

agency, Dr. von Braun was a strong proponent of the scientific exploration of space and the development of large launch vehicles for this purpose.

Meanwhile, the von Braun team was busy solving the theoretical and practical problems of rocketry. Already members of the group were studying the feasibility of larger boosters with much greater thrust and payload-carrying capability for orbital and deep space missions. Through dozens of Redstone and Jupiter static firings and test flights, they were resolving some of the difficulties in rocket design, propulsion, and performance.

Due to their foresight in planning and preparation, the ABMA group was ready for the United States' first launch of a satellite. Having anticipated the space age the rocket team responded quickly when launch was authorized. In January of 1958, the ABMA lofted America's first satellite, Explorer I, into orbit aboard the Army's Jupiter C rocket, just three months after authorization. During the next two years, the ABMA launched six other scientific satellites, including a Pioneer that orbited the sun.

The initial success with the Jupiter rocket spurred the von Braun team and the ABMA toward an even more ambitious big booster program, originally named the Juno, for advanced space missions. In 1959, a separate Defense Department organization, the Advanced Research Projects Agency (ARPA), authorized ABMA to begin a research and development program for a vehicle having a 1.5 million pound thrust capability. This tremendous advance was to be achieved by clustering eight available rocket engines into one stage. The major goal of the program was a demonstration static firing by the end of 1959. The Juno program was renamed Saturn in 1959, and soon thereafter the project received the highest national priority rating. Members of the rocket group in Huntsville were enthusiastic about the new project; they had been nurturing the concept for years, and they were eager to proceed.

In the meantime, NASA was founded in 1958 by an Act of Congress to support a vigorous civilian space program. The new space agency included elements from various existing laboratories and installations, but it did not have a strong capability for developing launch vehicles and propulsion systems. After extensive negotiations, the ABMA's Development Operations Division headed by Dr. von Braun and the Saturn project were transferred from the Department of Defense to NASA in 1960.

Huntsville-Madison County Public Library photo

Fireworks in downtown Huntsville to celebrate Explorer I launch

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The Huntsville Times

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Jupiter-C Puts Up Moon

Wail Of Sirens Brings In Era On Space Here

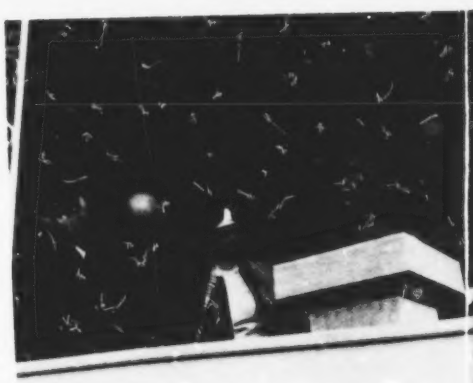
Thousands Gather On The Square For Noisy Success Demonstration

9 Labs Here Aided Project Of Launching

Eisenhower Officially Announces Huntsville Satellite Circles Globe

Weather Change Sped Launching

Army Reveals Second Moon Is Scheduled



President Eisenhower and Mrs. George C. Marshall at dedication ceremony for NASA's Marshall Space Flight Center

"After thousands of years of clinging to our planet, man is finally about to burst the bonds of terrestrial gravity and embark on the greatest voyage of his entire existence. . . the exploration of the space around him."
Dr. Wernher von Braun, 1958

This transfer strengthened the agency considerably and also guaranteed the rocket team's active participation in the scientific exploration of space.

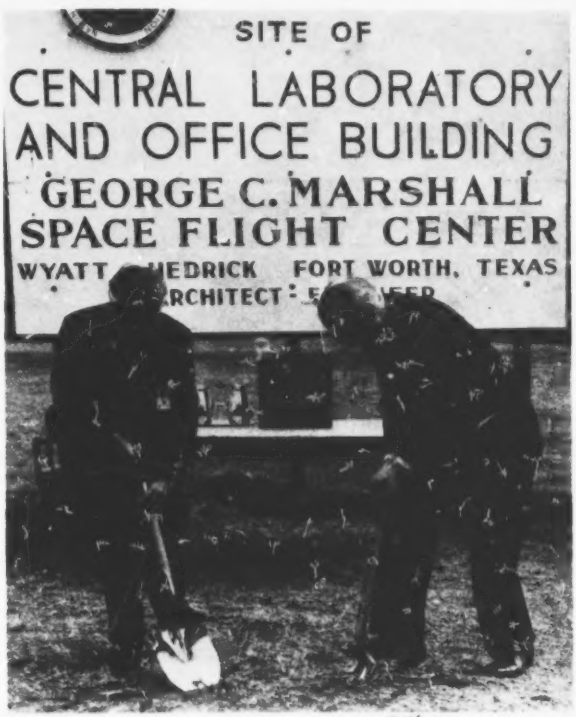
On July 1, 1960, the George C. Marshall Space Flight Center officially came into being as 4,670 civil servants previously associated with the Army became NASA personnel, and 1,840 acres of Arsenal property and facilities worth $100 million were transferred to the space agency. For several months, the Marshall group continued to work at the same desks in the same Army buildings. The new organization resembled the old, and the continuity of personnel and activity was hardly affected by the transfer. In addition to the Saturn project, Marshall assumed responsibility for the Juno II rocket, the 1.5 million pound thrust F-1 single engine, development of the Agena B stage of the Atlas and Thor boosters, development of the Centaur launch vehicle, and development of the Mercury-Redstone vehicle for NASA's first manned program, Project Mercury.

Dedicating the new NASA center in September, President Dwight Eisenhower remarked that General George C. Marshall, the distinguished soldier and statesman, was a builder of peace. The decision to name the center in his honor was also a fitting tribute to both the agency and the team of rocketry pioneers whose origins were in military research but who aimed for the peaceful scientific exploration of space.

Thus, when Marshall Space Flight Center opened for business in July of 1960 it was already a thriving enterprise. Its work force included many people who had already worked together for a decade or longer. Its founding director was Dr. Wernher von Braun, an advocate of space research and development activities for more than 20 years. Major programs were already established and in progress, and its organizational philosophy was in place. The new center had excellent laboratories for rocket propulsion system design, development, manufacturing, and testing. Its technical capabilities were unsurpassed, and its morale and team spirit were vigorous.

The Center was born in an atmosphere of urgency, at a time when the nation's goals in space were not yet clearly focused. The space environment was unfamiliar territory and there were many uncertainties about appropriate technology and suitable missions. To those who had been working with rockets, the next step seemed obvious: bigger, more powerful boosters to place communications and weather satellites into orbit, to send planetary probes into deep space, to carry people and their living quarters or workshops into space, and to begin studying and using space for the benefit of all mankind.

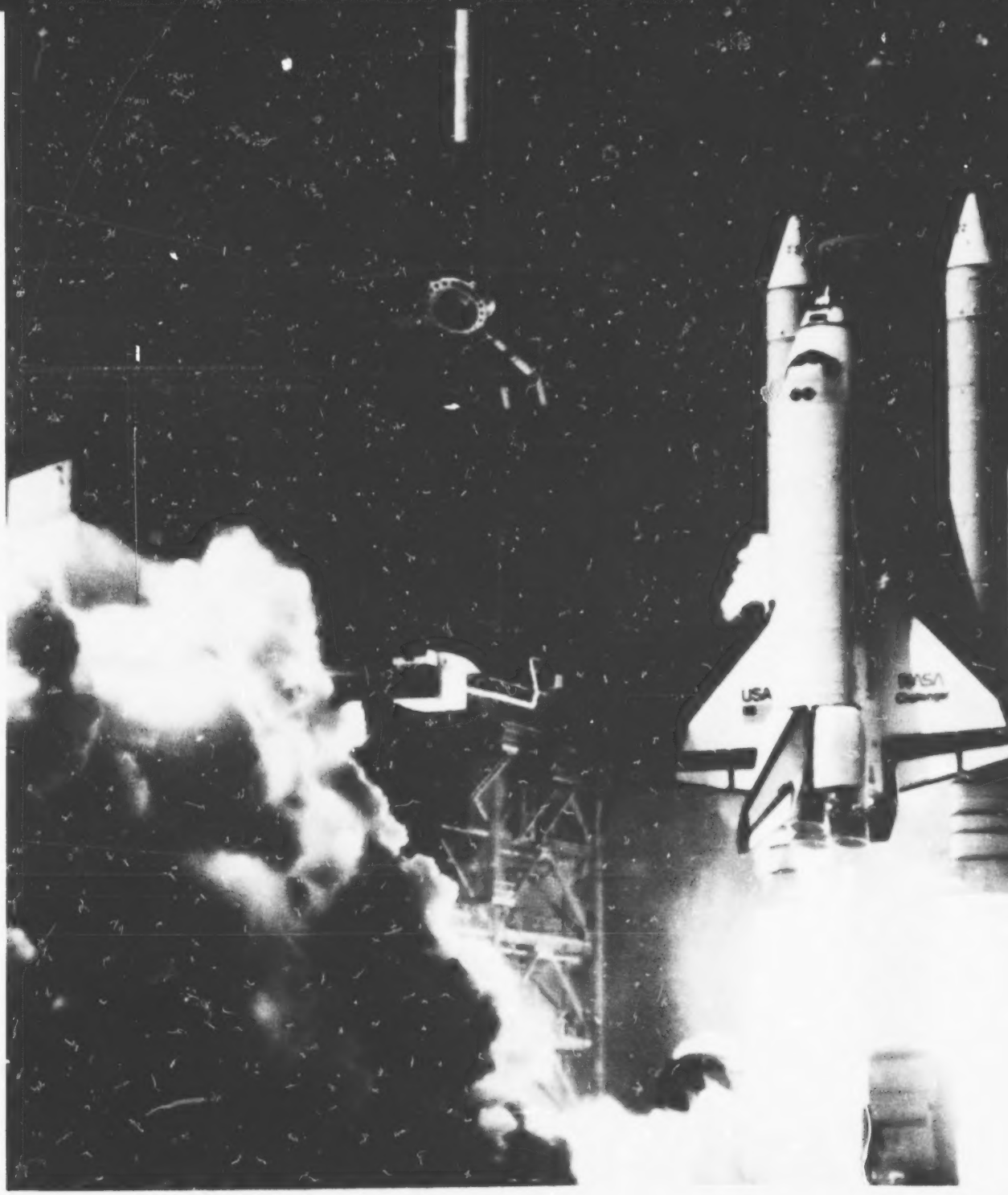
While public consensus was forming, the cadre of rocket experts in Huntsville proceeded apace with the task of developing awesome new launch vehicles – the massive Saturn family. Despite the unparalleled experience and expertise that made this group an invaluable national resource, the Saturn project challenged all their technical and managerial abilities. From this beginning arose the traditions that still characterize Marshall Space Flight Center today: engineering excellence and the disciplined concentration of energy essential for success. ■



Breaking new ground for the nation's space program

THRUST INTO SPACE:

PROPULSION SYSTEMS AND LAUNCH VEHICLES

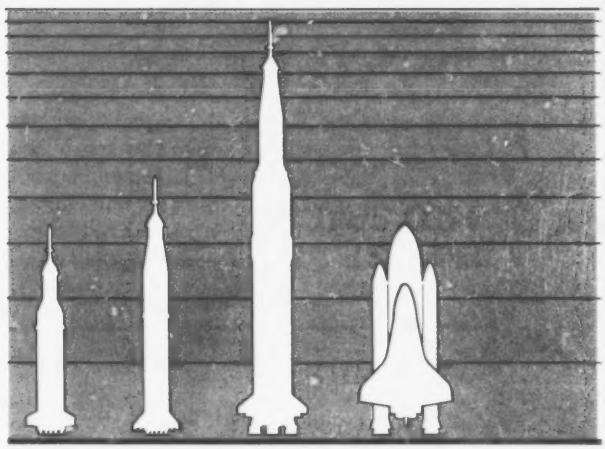


In a blaze of light and rumbling thunder, a space vehicle rises from its launch pad. For most observers, a lift-off marks a beginning, a take-off, the start of an adventure. For NASA engineers, however, a launch is a climactic event, the culmination of years of hard work. While others watch expectantly, those who have designed or built a vehicle wait tensely for the moment of relief and jubilation, the spectacular moment of proof that their work has been done well.

Marshall Space Flight Center developed the engines and vehicles that boosted our nation into space. Transportation systems have been a crucial part of the Center's business, from the early Redstone rockets to the sophisticated Saturn launch vehicles and on to the Space Shuttle and the advanced craft that will serve us in the Space Station era. At every stage, the development of propulsion systems and vehicles for space flight has posed technical and managerial challenges. There was no precedent for the pioneering work of establishing safe, reliable transportation service into space. The history of this Marshall Center achievement is one of problems solved, challenges met, and successes recorded.

"I think we've got a fantastic and remarkable capability here. We're really not too far . . . from going to the stars."

John Young
Commander, STS-1, 1981



THRUST INTO SPACE

Saturn

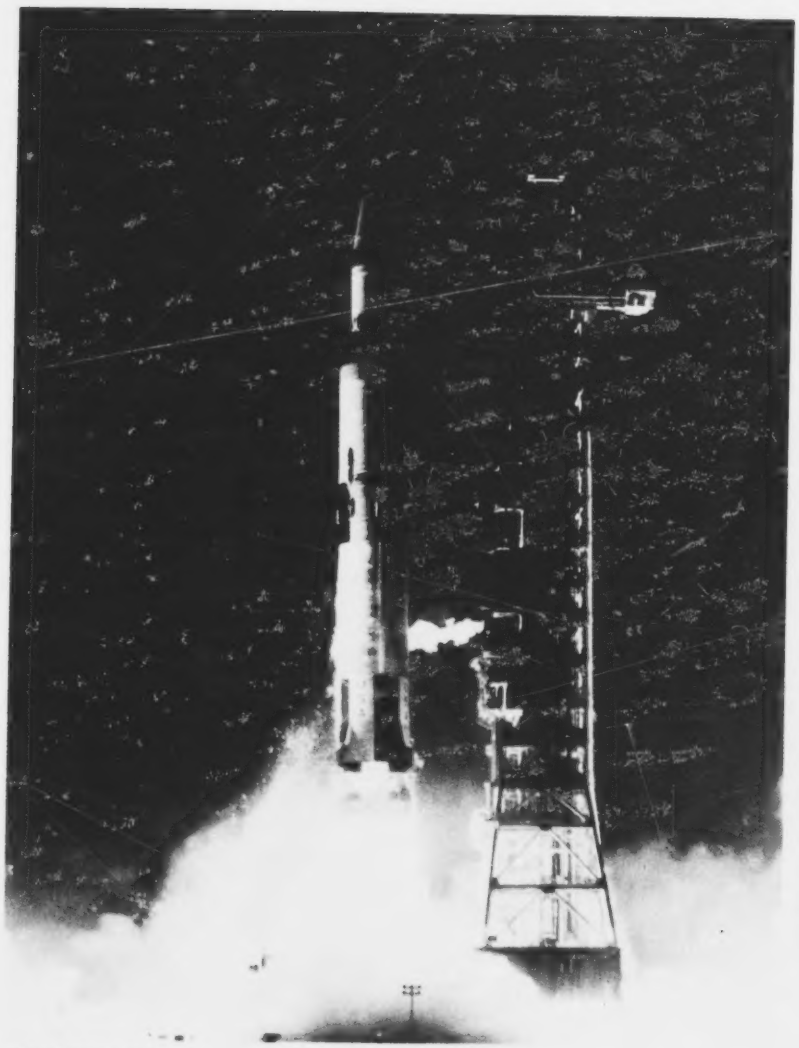
Marshall Space Flight Center came into being with a charter to develop a launch vehicle of unprecedented size and power. As the pace of the space program quickened in the late 1950's, a bold leap was urgently needed to establish American technological pre-eminence. That advance, of almost inconceivable proportions, was the Saturn series – the Saturn I, Saturn IB, and Saturn V launch vehicles.

The new vehicles would be gigantic compared to their predecessors, which were themselves barely off the drawing boards and test stands. They would have remarkable thrust and lift capability. Whereas the 70-foot Redstone generated about 75,000 pounds of thrust for suborbital flight, the Saturn I was first envisioned as a 165-foot, 1.5 million pound thrust giant capable of attaining Earth orbit. Those initial specifications were soon revised upward, and the largest member of the family, the towering 363-foot Saturn V, ultimately became a multi-stage, multi-engine vehicle standing taller than the Statue of Liberty. With a first-stage thrust of 7.5 million pounds and another 1.2 million pounds in combined upper-stage thrust, the Saturn V was capable of sending man to the moon.

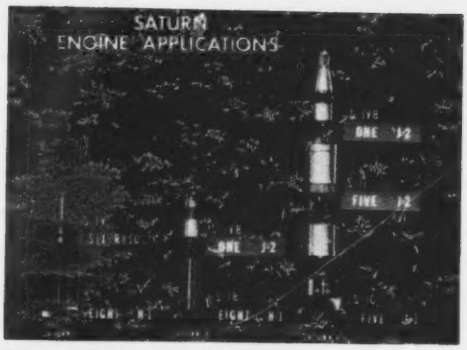
Although the origins of the Saturn concept lay in ongoing rocket research within the Army Ballistic Missile Agency and other military programs, a strong impetus to the Saturn program was President John F. Kennedy's 1961 announcement of the nation's foremost goal in space: a manned lunar landing within the decade. As early as 1959, NASA was already looking toward this goal in its long-range planning, but not within the same time frame; a lunar landing in the early 1970's was contemplated. Now, before a single American had been thrust into orbit, NASA and the nation were committed to an extremely ambitious

"I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to Earth."

President John F. Kennedy
May 25, 1961



First Saturn V launch (Apollo 4), November 9, 1967



Saturn engines and stages

endeavor. The Saturn program, the Marshall Center's first major responsibility, crystallized about this goal. The new family of extraordinarily large launch vehicles was required for the Apollo lunar missions.

Marshall Space Flight Center was a fountainhead of activity during the months of early Saturn-Apollo planning. NASA had decided to use the Army's Redstone ballistic missile and the larger Air Force Atlas missile as boosters for Project Mercury, which would lay the foundations of manned space flight in preparation for the Apollo missions to the moon. To Marshall fell the responsibility of modifying the Redstone vehicle for the first manned suborbital missions.

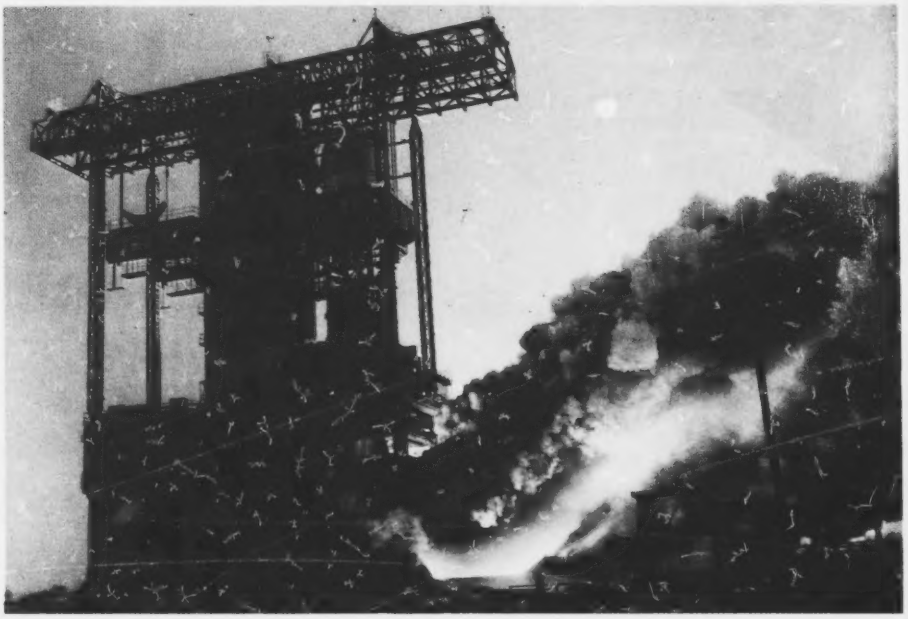
After several unmanned test launches in 1960 and a flight by the chimpanzee "Ham" in early 1961, the Mercury-Redstone systems were judged flight-worthy for a manned mission. In May of 1961, Marshall's Redstone vehicle boosted America's first astronaut, Alan B. Shepard, on a successful but brief suborbital flight. A modified Redstone was used on a subsequent Project Mercury flight, and Marshall's track record of successful launches began to grow convincingly.

The original Marshall organization included a Launch Operations Directorate responsible for launching test flights and the Mercury-Redstone flights. In 1962, this Marshall launch team moved to Cape Canaveral and its leader, Dr. Kurt Debus, became the first Director of the Launch Operations Center there, later renamed as Kennedy Space Center. An exceptionally close working relationship between the two Centers has continued since that time.

For the next several years, other elements of NASA methodically perfected spacecraft systems and orbital rendezvous techniques through the Mercury and Gemini missions. Meanwhile, Marshall surged ahead to prepare the launch vehicle for the Apollo lunar missions.

Scaling Up

In the interests of time and economy, the developers of the Saturn vehicles relied heavily on contemporary rocket design and propulsion technology. Nevertheless, the Saturn represented a dramatic departure from early single-engine, single-stage rockets. To achieve the thrust necessary for manned lunar missions, it was essential to develop a multistage vehicle with clusters of engines and to use higher performance propellants and propulsion systems. Advanced missions and heavy payloads meant more engines, bigger launch vehicles, and higher-energy fuels.



Saturn I test firing at Marshall

Scaling up to the massive Saturn dimensions was a major challenge. Even though prototypes of some components existed, they were not as large as the new vehicle required. In addition to basic advances in rocket technology, related developments in materials, analytical techniques, tooling, fabrication techniques, and test facilities were necessary. In fact, rapid advances in the state of the art were necessary in almost every technical area.

How did the Marshall Center turn the Saturn concept into reality? What technical challenges did Marshall people meet, and what did they contribute to the state of the art in critical engineering disciplines? These questions have been explored in detail in other documents; a summary here will distill the essence of the Marshall Center's achievement.

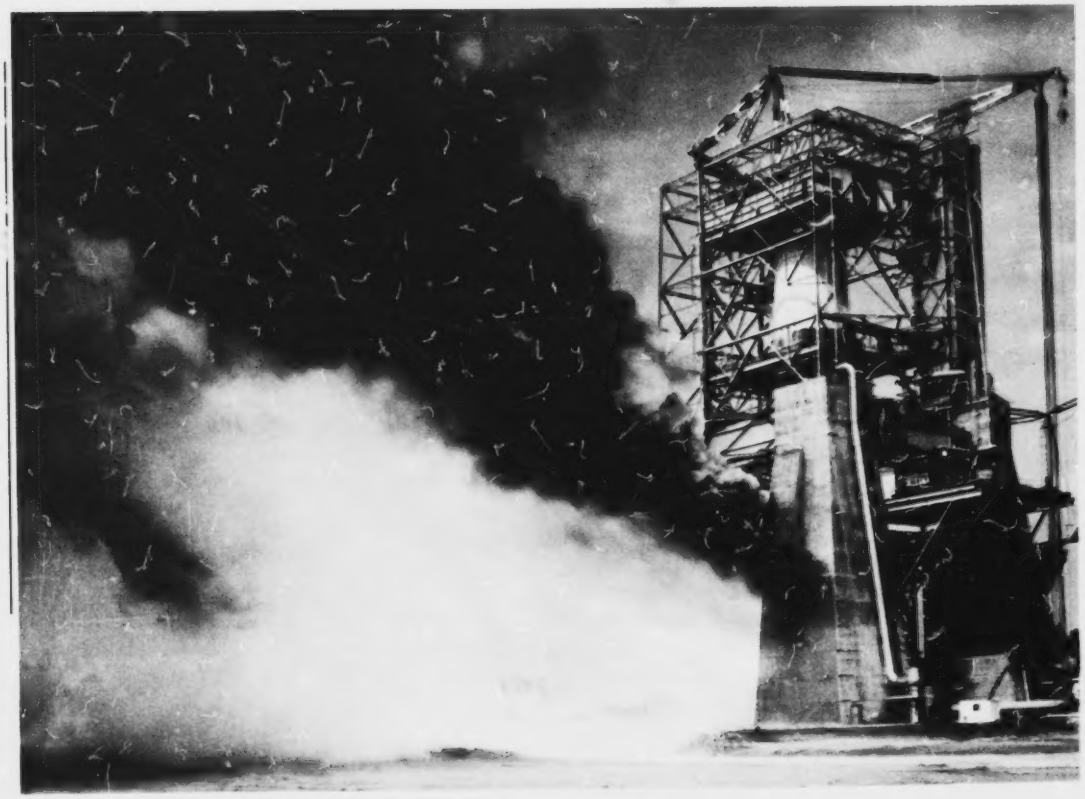
To manage the tasks of developing, producing, and integrating the large multistage vehicles, Marshall's initial organization included a Saturn Systems Office with responsibility for managing all aspects of the Saturn program. As the program evolved and matured, the Systems Office was subdivided into three project offices for Saturn I/IB, Saturn V, and engines. The project offices in turn were subdivided into offices for each vehicle stage or engine. By 1963, a large amount of Saturn work was being performed under contracts, and the Saturn management offices were organized under the aegis of a new Industrial Operations Directorate.

Technical expertise for Saturn was provided by the Center's nine engineering laboratories: Aero-Astrodynamics, Astrionics, Computation, Manufacturing, Propulsion and Vehicles, Quality and Reliability Assurance, Test, Launch Vehicle Operations, and Research Projects. These specialized discipline laboratories, which had their origins in the ABMA organization, constituted most of the Research and Development Operations Directorate. Their importance to the Saturn program was incalculable; the laboratories continually pushed the limits of the state of the art in all fields to develop the designs, materials, and technology that made Saturn possible. A major factor in the success of the program was the creative technical excellence of the Marshall Center laboratories.

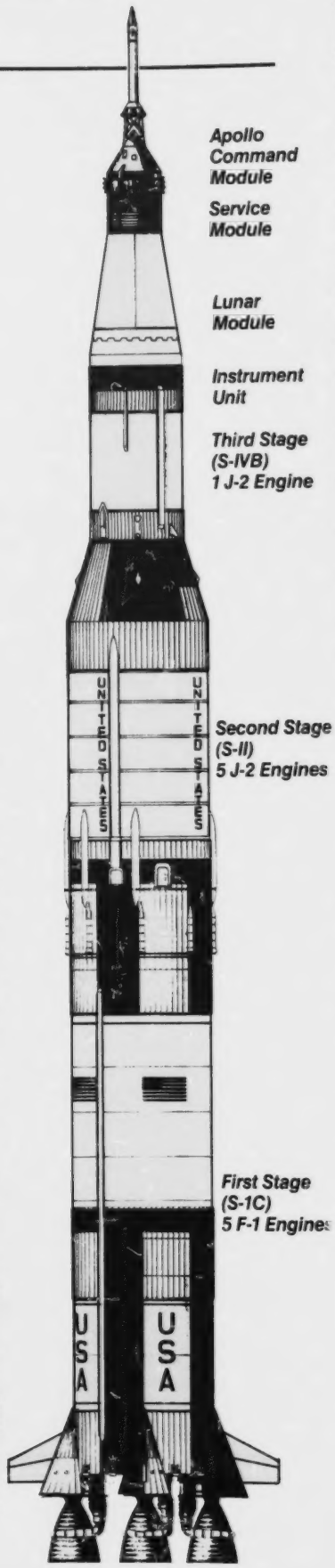
The Saturn family of boosters included three vehicles: the Saturn I and IB for development purposes and early Apollo flights, and the Saturn V for the actual lunar missions. Even before the Saturn project was officially NASA's responsibility, the von Braun group and other space program officials vigorously debated the question of configuration. It was a foregone conclusion that the giant boosters would need several stages and clusters of engines, but dozens of arrangements were possible. Deciding upon the basic architecture of each Saturn vehicle was a dilemma resolved by careful deliberation. How many stages, of what height and diameter, how many engines per stage, what type and arrangement of engines would stack up to make the best booster? The Saturns were

"Few of man's technological endeavors compare in scope of significance to the development of the Saturn family of launch vehicles. . . . Saturn was an engineering masterpiece."

Dr. W.R. Lucas



Test firing of Saturn IC stage at MSFC



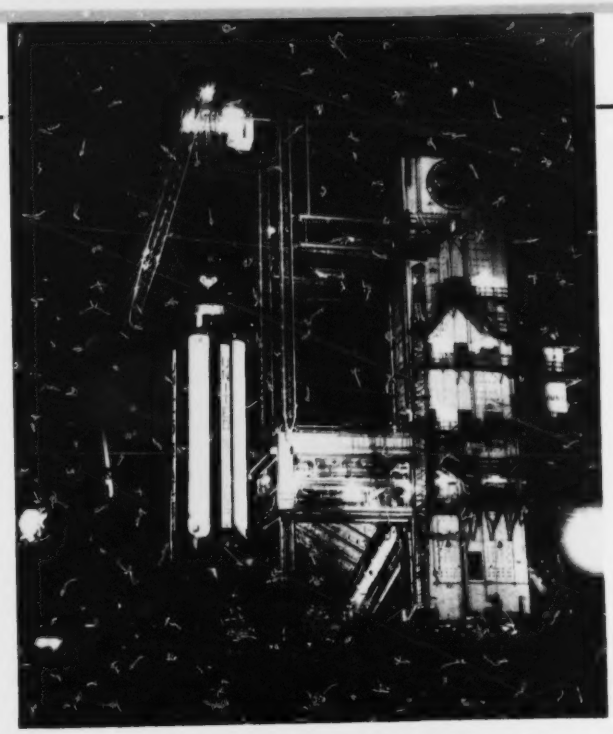
hybrid vehicles combining newly designed clustered-engine stages and new engine technology.

Marshall Space Flight Center personnel were deeply involved in the vehicle concept work. The decision was made in early planning studies to use a first-stage cluster of eight modified Jupiter engines burning a kerosene distillate fuel called RP-1 with liquid oxygen. The choice of upper-stage engines and configurations, however, was less clear. After initial consideration of various conventional missile stages, NASA opted in 1959 to use new liquid hydrogen engines in the second and third stages. Saturn configurations stayed in flux as various concepts for stages and engines were evaluated and parallel development efforts proceeded. By 1962, the broad configuration issue was settled, though many interfacing details remained to be worked out.

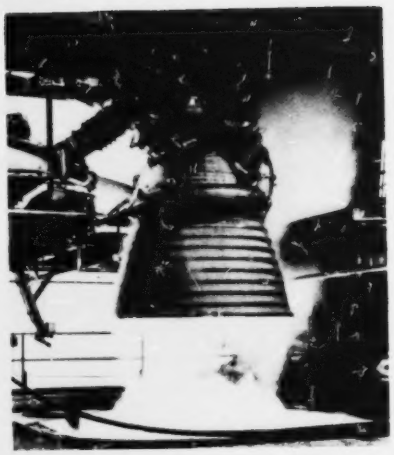
Marshall Space Flight Center carried out development, testing, and production of the Saturn I first stage in-house until Chrysler Corporation became the prime contractor in late 1961. The in-house effort established the basic design for clustered engines and clustered propellant tanks, the pumping scheme for a steady and balanced propellant flow from tanks to engines, the structural skeleton and skin for the unusually large stage, and the guidance and control mechanisms for steering the vehicle during powered flight.

The flawless first launch in October of 1961 validated the Saturn vehicle concept nurtured at Marshall. In ten successful Saturn I launches between October 1961 and July 1965, engine performance and vehicle reliability were convincingly demonstrated. Eight of the ten Saturn I first stage boosters were built at Marshall, the others by Chrysler Corporation Space Division. Five second stages (two for testing and three for flight, all unpowered "dummies") were built at Marshall before Douglas Aircraft Company began to supply them under contract. In addition, five Saturn V first stages (three for ground tests and two for flight) were fabricated in-house at Marshall. After this initial production, all stages of the three Saturn vehicles were produced by contractors (Douglas, North American, IBM, Rocketdyne, Pratt and Whitney, and Boeing) under Marshall Center management.

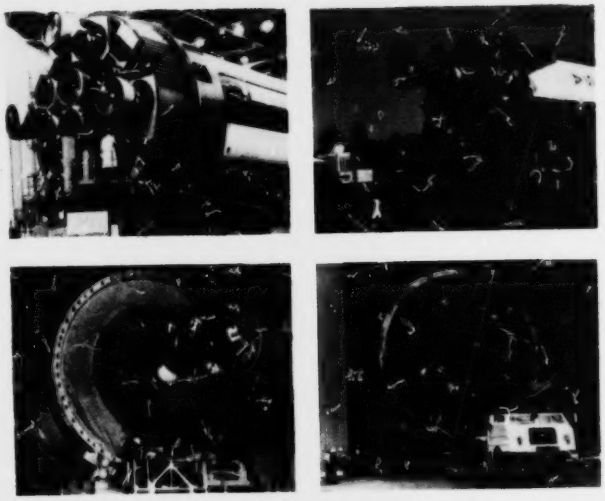
Launch vehicle configuration was contingent upon powerful rocket engines, the prerequisite for space flight. Much of the Marshall Center's early effort was directed toward advanced engine technology and higher-energy propellants. Fuel-efficiency assessments pointed to liquefied gases as the most



Working overtime to keep Saturn on schedule



J-2 engine static firing



Saturn launch vehicle engines

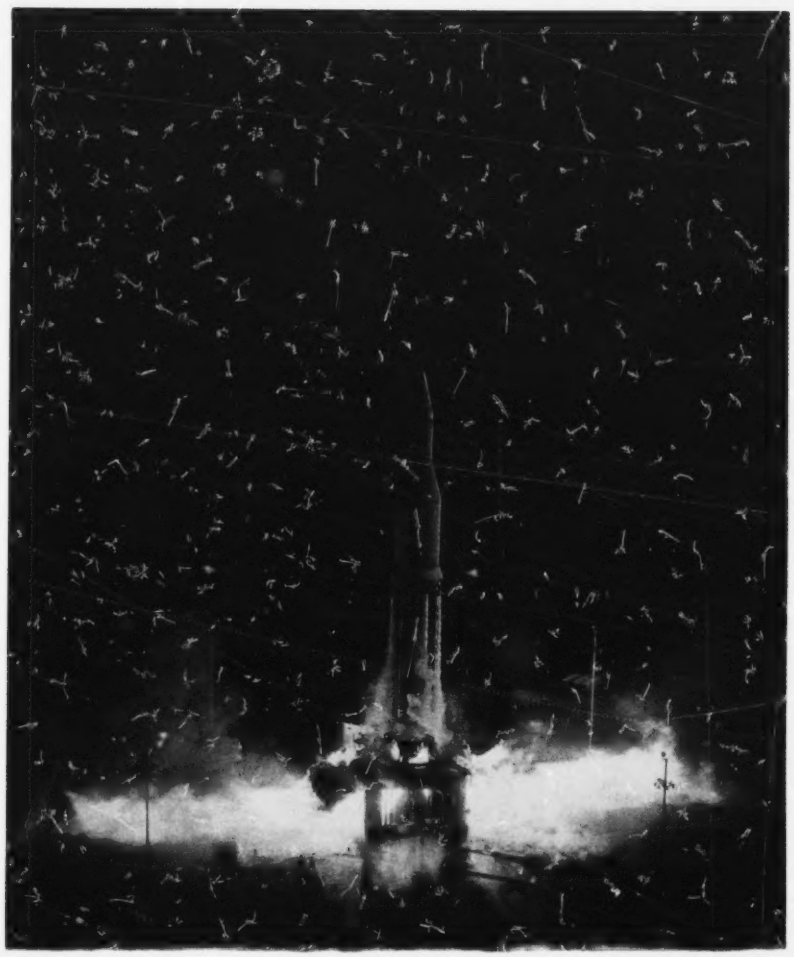
THRUST INTO SPACE

promising new propellants for advanced missions, and to liquid hydrogen in particular, because conventional propellants could not supply the necessary thrust and high performance for heavy-payload lunar missions requiring escape velocities.

When liquid hydrogen was selected for Saturn's upper stages, its use as an engine fuel was experimental. In addition to proving its performance, engineers faced a host of logistical problems associated with storing, pumping, and transporting the fuel, which is highly explosive and must be maintained at extremely low (cryogenic) temperatures, more than 400°F below zero. Advances in insulation materials and in the design of large cryogenic storage tanks and pumping systems were required by the selection of liquid hydrogen as a propellant for Saturn upper stages.

As the Saturn program evolved, the Marshall Center worked closely with contractors to improve or develop engines for each vehicle stage. Two first-stage engines (the H-1 and F-1) and two high-energy upper stage engines (the RL-10 and J-2) were ushered through research and development, testing, production, and launch. The most visible (and audible) evidence of Marshall's role was the static firing test activity in Huntsville. Local citizens had frequent thunderous reminders that the space program was in progress just next door.

Early Saturn I launch, with "dummy" second stage and payload



The first-stage engines used a conventional kerosene-liquid oxygen propellant and existing engine concepts. The main engineering challenges were to cluster and enlarge the engines for much higher thrust, which introduced problems that required innovative solutions. For example, some of the engines were gimballed for directional control of the vehicle powered by the combined thrust of eight engines. New ducting and venting techniques were used to deliver propellants to the multiple engines. Manufacturing problems resulted in new materials and manufacturing processes. Turbopumps and thrust chambers were improved for uniform propellant flow and combustion under very severe temperatures and pressures. Special instrumentation was developed to evaluate engine performance under dynamic conditions. While the first-stage engines had a heritage of proven technology, scaling up resulted in many advances.

A prototype uprated H-1 engine developed by Rocketdyne was first tested in 1958; an eight-engine cluster was tested and flight rated at Marshall in 1960, during the Center's first year. Models of this workhorse ranged in thrust from 165,000 to 205,000 pounds per engine, for a total thrust of more than a million pounds in a Saturn I or IB first-stage cluster. The F-1 engine, developed to meet the greater thrust demands for Saturn V launches, yielded an awesome 7.5 million pounds of thrust in a five-engine first-stage cluster. Also developed by Rocketdyne, this engine was first tested in 1961, then tested in a cluster at Marshall in 1963, and first flown in 1967. Both first-stage engines proved highly reliable.

While suitable engines for Saturn first stages were developed by enlarging and modifying existing designs, there were no available liquid hydrogen propulsion systems. Without proven technology, NASA undertook the development of entirely new engines for Saturn upper stages. Management responsibility for this pioneering engine work was assigned to Marshall Space Flight Center at its founding. The new engines represented major technological breakthroughs in propulsion system design and performance.

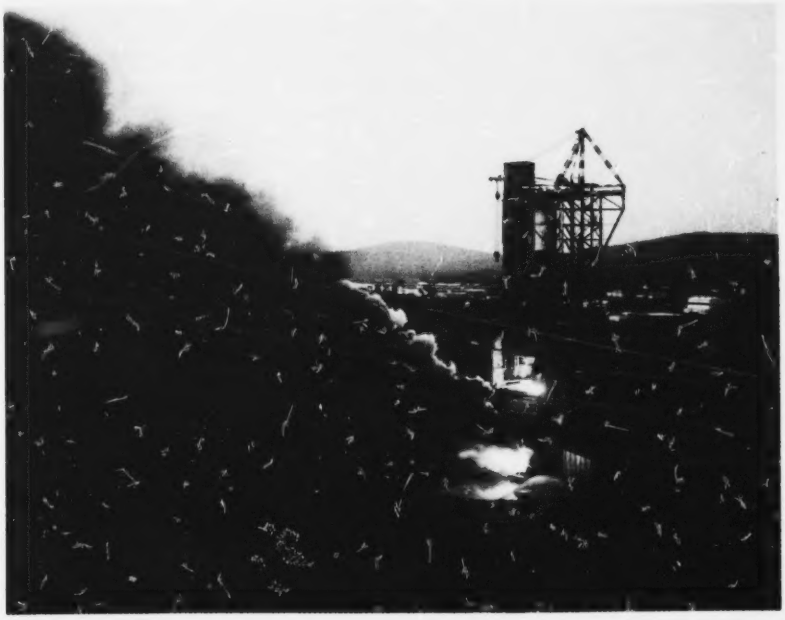
The initial upper stage engines used in Saturn I vehicles were derived from the RL-10 hydrogen/oxygen engine under consideration in the late 1950's by the Air Force. When built into an upper stage, this engine would enable

Atlas missiles to launch heavier payloads, such as communications satellites. NASA inherited responsibility for the RL-10 engine under development by Pratt & Whitney, and by 1959 it was destined for use in the Saturn IB upper stage. Engine testing occurred at Marshall Space Flight Center and other sites, and by 1961 the high-performance RL-10 liquid hydrogen engine was flight rated. The selected configuration for the Saturn I second stage was a cluster of six engines, each having 15,000 pounds of thrust; its first flight occurred in 1964.

Concurrently with RL-10 engine development, NASA was planning ahead to liquid hydrogen engines of even greater thrust, 200,000 pounds each, to be used singly or in clusters. Beginning in 1960, development of the J-2 engine was undertaken by Rocketdyne under Marshall Center management. These huge engines became the powerhouse for Saturn IB and Saturn V upper stages. A single J-2 engine was used in the Saturn IB second stage and Saturn V third stage; five of these engines were clustered in the Saturn V second stage for a million pounds of thrust. Following successful tests in 1962, the engine entered production in 1963 and was first flown in 1965.

As manager of the engine development projects, the Marshall Center was immersed in all the design issues and technical problems facing its contractors. Together, the government-industry team faced the challenges of scaling up existing concepts and simultaneously working out new technology. The Center relied on its in-house laboratory expertise in propulsion systems, metallurgical and materials research, fluid dynamics, structures, dynamics, and other disciplines for the necessary engineering advances. Notable achievements included the application of lightweight, durable materials capable of withstanding extreme temperatures and stress, new heat

Altogether the Saturn V engines produced as much power as 85 Hoover Dams.



F-1 engine static firing test at Marshall

J-2 engine assembly line at Rocketdyne facility in Canoga Park, California

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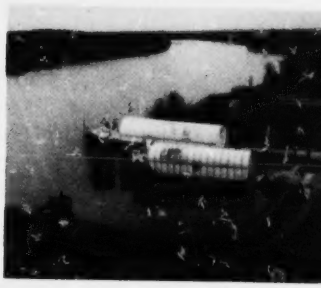
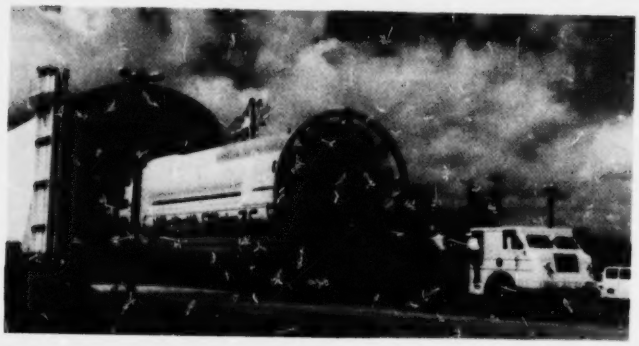
treatment for alloys, innovations in turbomachinery design for improved efficiency, and myriad other improvements in component designs and fabrication techniques to meet the unique operational demands of the Saturn vehicles. Throughout the 1960's, the Center also maintained engine testing programs in Huntsville concurrent with testing at contractor sites.

At its founding, Marshall had inherited the Army's Jupiter and Redstone test stands, but much larger facilities were needed for Saturn V testing and for manufacture of the giant stages. Besides expanding its own facilities, Marshall acquired three additional installations elsewhere in the early 1960's. In a related expansion, Marshall acquired or built barges and docks to develop a suitable system for transporting the huge Saturn elements to the launch site. All of these facilities operated under the jurisdiction of Marshall Space Flight Center. The complexity of this construction and logistics effort was a major challenge that required a substantial investment.

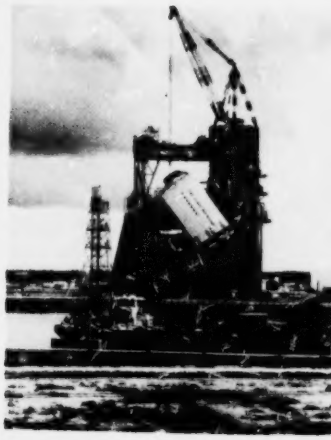
From 1960 to 1964, existing test stands at Marshall were remodeled and a sizable new test area was developed. The new towers erected for propulsion and structural dynamic



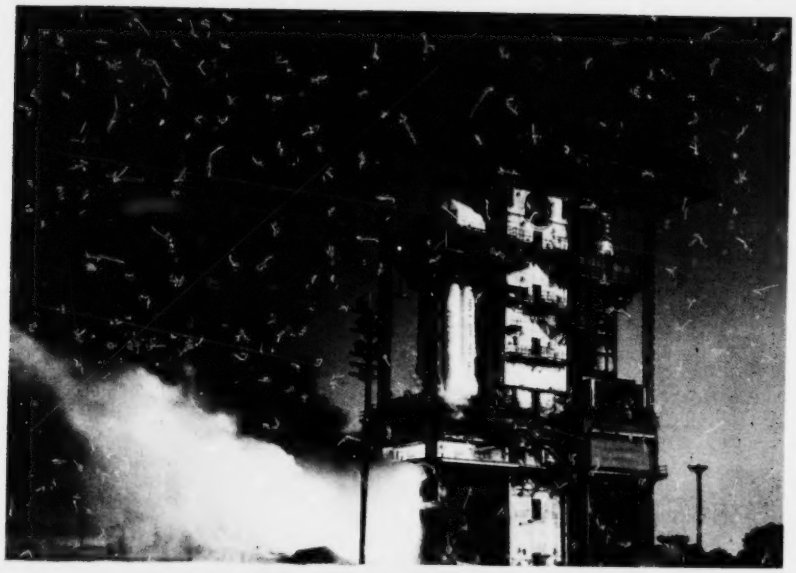
The Center's barge dock on the Tennessee River



Transport of Saturn S-IB stage from dock to MSFC test stand



Marshall's Mississippi Test Facility, where Saturn stages began journey to Huntsville



Saturn IB static test at the Marshall Center

Temporary quarters in the Huntsville Industrial Center as MSFC grew

tests were among the tallest buildings in the state. They also made up a comprehensive test complex for static firings of extremely powerful engines, storage and pumping of cryogenic fuels, and structural evaluation of inordinately large objects. The Marshall test areas were unique within the nation and the free world, and they remain so today because they were constructed with foresight to meet future as well as original needs. The Center also expanded its local production facilities for in-house fabrication of the early Saturn stages.

The Michoud Assembly Facility in New Orleans, Louisiana, a component facility of the Marshall Space Flight Center, became the manufacturing and assembly site for the Saturn IB and Saturn V first stages. Jointly occupied by the two prime contractors, Chrysler and Boeing, the plant had over 3 million square feet of production and office space, with 43 acres under one roof. The facility, located on the Gulf intracoastal waterway, was well situated for barge transport of the stages to test and launch sites.

Nearby in Bay St. Louis, Mississippi, the Marshall Center constructed a massive new engine test complex. Three huge test stands surrounded by laboratories, fuel storage tanks, and support facilities rose from the wilderness. Saturn stages were test fired and qualified here by a contractor workforce under Marshall management. Originally a part of the Marshall Center, the Mississippi Test Facility later became an independent NASA installation.

A government-owned computer facility in Slidell, Louisiana was enlisted to support the Michoud plant and Mississippi test site. A component installation of the Marshall Center, the Slidell Computer Complex provided critical data processing services for Saturn test, checkout, simulation, and engineering activities.

In parallel with the development of engines and stages, Marshall Space Flight Center was engaged in developing the Saturn vehicle's instrument unit for guidance, navigation, and control. This "brain" controlled all the ignition sequences, stage separations, guidance and control, and telemetry functions to keep the vehicle operating properly and on course. Begun as an in-house project, which evolved through several versions, the sophisticated unit eventually was contracted to IBM for final design and manufacture. Its continuing refinement was marked by notable advances in computer memory, logic, and instrument design using new alloys and miniaturization techniques that found a ready commercial market in a variety of consumer products.

Building Confidence

The key word for the Saturn development effort was performance. Given a highly visible and costly space program, strong pressure to meet goals on schedule, and the importance of crew safety, everything possible was done to ensure the reliable performance of every Saturn element. As program manager, Marshall Space Flight Center led the way in establishing both technical and managerial practices that built confidence in the Saturn vehicles. The result was 32 consecutive successful Saturn launches, the complete program including 9 lunar missions. A fleet of extraordinarily reliable vehicles boosted the space program to success.

The confidence factor derived from conservative design, extensive testing, and stringent quality control, all based on meticulous attention to detail. Simplicity, building blocks, and tests were the key tenets of this philosophy.

At virtually every point, Marshall engineers favored design simplicity. Undue complexity introduced greater risks that could jeopardize the schedule or the entire program. As they scaled up existing components and systems, engineers kept a keen eye on ways to streamline the designs. While they developed designs for new items, they also looked for ways to

Construction of towering new test stands at Marshall, 1960-1964

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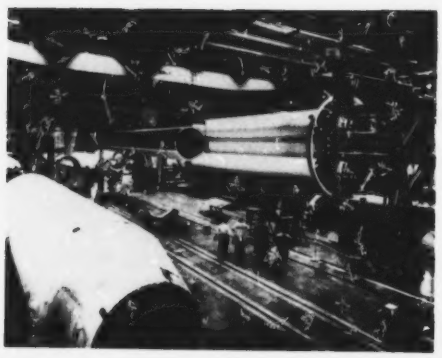
make things work without burdensome complexities. The novel J-2 engine design admirably illustrated this principle; many components in this propulsion system served more than one purpose.

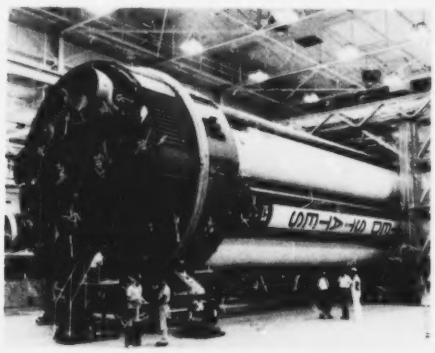
Marshall engineers and managers favored a building block approach to the ambitious Saturn program. To ensure steady progress toward a launch vehicle that had no precedent, they organized the development effort in phases to prove the technology for each phase in a relentless step-by-step fashion. Each major element – an engine or an entire stage, for example – was a building block that was added to the configuration in due course. Systems were gradually built up as components were tested and proved; likewise, the vehicle gradually evolved as one element after another was added and exercised.

The Saturn I launch series illustrated this building block approach to development by successive additions: initially only the first stage was live, with a dummy upper stage; after more checkout flights, a live upper stage was added; then a functional payload was added. The Saturn I itself was a building block for the IB vehicle, which in turn was a building block for the Saturn V. This methodical development scheme proved so reliable that the Saturn I was rated operational three flights ahead of schedule, and the first Saturn V flight was an "all-up" mission with all stages live. The decision for an all-up first launch was a bold break from precedent, made after much deliberation; in balance against the inherent risk of initial failures was the confidence factor so painstakingly nurtured at Marshall.

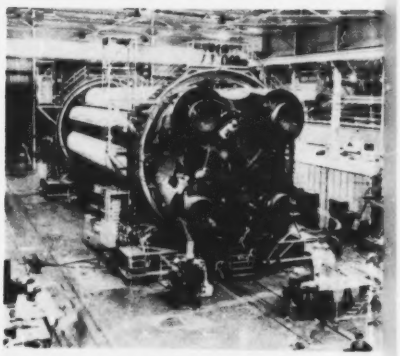
Marshall also was firmly committed to rigorous testing. To avoid surprises in flight, engineers subjected Saturn components to every conceivable stress and strain anticipated during a mission. Extremes of temperatures, pressure, vacuum, and vibration even greater than those predicted for launch and space flight were devised in laboratories and test stands. New facilities were built and existing test facilities at both the Center and at contractor locations were scaled up to accommodate the massive Saturn elements. Saturn test and checkout activities spawned remarkable advances in electronic simulators and automated test equipment. This apparatus could



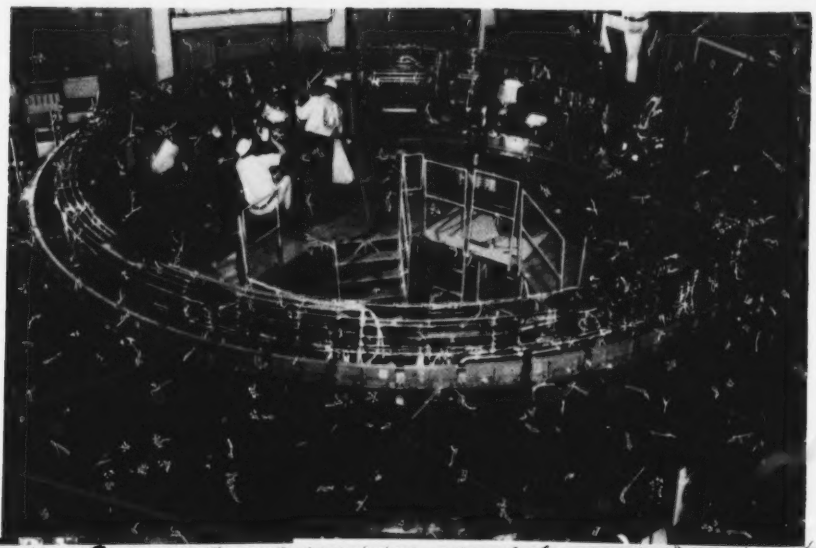
Saturn I build-up at MSFC



Installation of engines



Checkout of the completed booster



Assembly of the Instrument Unit, Saturn's complex "brain" for guidance, navigation and control

create a high-fidelity simulation of launch and flight or could take the pulse of hundreds of different parts to provide engineers with detailed performance data. In addition to test and checkout data, hundreds of measurements of actual flight performance were collected via telemetry.

The emphasis on performance and reliability penetrated all levels of the Saturn program from top-tier management to production line workers. The strategy of technical competence – of doing things right – was evident everywhere. Dr. von Braun, for example, expressed a "dirty hands" philosophy, encouraging Center personnel to keep themselves steeped in technical matters. This would make them better engineers and better managers of contract work. One of the Saturn program's best insurance policies was the distinctive competence resident in Marshall's laboratories and shops.

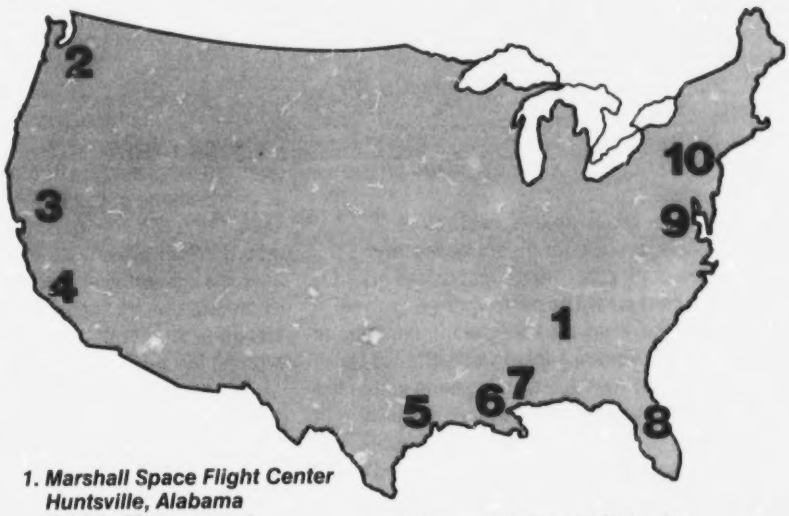
Although all Saturn launches were successful, there were occasional problems and moments of anxiety. A particular cause of concern on the first Saturn V flights was the "Pogo effect," vertical vibrations that occurred during powered flight. Lasting only a few seconds, these "bounces" increased stress on the vehicle. A Pogo task force did the necessary detective work to understand the Pogo phenomenon and implement corrective measures. The vibrations were successfully suppressed in time for the first manned Saturn V flight.

Working as a Team

Marshall Space Flight Center faced a management challenge beyond the scope of any previous technological endeavor. As many as 20,000 contractor companies across the nation were involved in producing the millions of parts that made up each Saturn launch vehicle. Furthermore, the engines and stages for the three different vehicles were evolving rapidly and in parallel, which complicated planning and coordination. To stay abreast of the status of all program activities and to foster reliability everywhere, the Center used a number of new management, systems integration, and program control methods both in-house and in the contractors' territory.

Teamwork characterized Marshall's relationships with its contractors. As the Saturn program evolved in scope, the development and production requirements exceeded the Center's capacity to do all work in-house. Therefore, the Center set about building a strong government-industry-university team with joint participation in working groups and extensive Marshall involvement in contractor activities. In this tripartite endeavor, the academic community contributed substantially to study and design activities, and the industrial community played major roles in development and manufacturing. This mutually beneficial cooperation resulted in the successful Saturn program.

The purpose of the teamwork philosophy was to ensure success by frequent and candid interactions between the government customer and the industrial supplier. This was accomplished by formal and informal meetings, by periodic progress reviews, and in most cases by a resident management office at the prime contractor sites staffed by Marshall personnel. Such close coordination and monitoring ensured that problems were recognized and resolved early, with minimal impact on costs or schedule.



1. ***Marshall Space Flight Center***
   Huntsville, Alabama
   Vehicle Management
   Boeing
   Systems Engineering
   General Electric
   Ground Support Equipment
   IBM
   Instrument Units
2. ***Boeing***
   Kent, Washington
   Lunar Roving Vehicle
3. ***SACTO Test Facility***
   Douglas Aircraft
   Sacramento, California
   S-IVB Test Operations
4. ***McDonnell Douglas***
   Huntington Beach, California
   S-IVB
   North American Rockwell
   Seal Beach, California
   S-II
   North American Rockwell
   Canoga Park, California
   H-1, J-2, F-1 engines
5. ***Manned Spacecraft Center***
   Houston, Texas
   Spacecraft, Mission Control
6. ***Michoud Assembly Facility***
   New Orleans, Louisiana
   Boeing
   S-IC
   Chrysler
   Saturn IB
7. ***Mississippi Test Facility***
   Bay St. Louis, Mississippi
   S-IC & S-II Test Operations
8. ***Kennedy Space Center***
   Launch Operations
9. ***NASA Headquarters***
   Washington, D.C.
10. ***Bendix***
    Teterboro, New Jersey
    Inertial Guidance Platform

A special application of team effort was the "Tiger Team." Technical performance has always been a critical and untouchable constant at Marshall. Therefore, when a difficult technical problem occurred, the Center identified a group of experts from the relevant laboratory disciplines to examine and penetrate the problem on-site. After thorough study to understand the intricacies of the problem and systematically evaluate alternatives, the team continued its focused effort until a workable, effective, and reliable solution was achieved and implemented. The Tiger Team concept that originated with the Saturn program subsequently remained a valuable means of resolving technical problems with dispatch.

The evolutionary nature of Saturn development activities created a need for careful configuration control. Marshall established stringent new guidelines for documenting all design specifications, design changes, engineering discrepancies, and related matters that could affect the integrity of any Saturn elements or their interface characteristics. For a reliable launch vehicle, everything had to mate exactly. There could be no surprises on the launch pad.

To further motivate the contractors, Marshall began to offer incentive fee and award fee contracts. These incentives encouraged the best possible performance to meet hardware deliveries on schedule. Incentives at the individual worker's level were offered by Manned Flight Awareness programs within the agency and at contractor plants to remind employees of the importance of their work. The message was clear: No one could afford to make mistakes.

In-house, Marshall developed several very effective teamwork techniques that promoted accountability – keeping track of who was responsible for what – and enabled managers to make well-informed decisions. From the outset, Marshall had a democratic propensity for convening committees, working groups, and panels to resolve problems or advise policy. An important device for fostering such teamwork was the Saturn Program Control Center, a briefing room outfitted with charts, projection screens, closed-circuit audio and television, and other aids for communication and information display. A hub of activity for several years, this was the place where managers met to monitor progress and keep the program's course on target.

Saturn Legacies

As the Marshall Center's first major assignment, and a spectacularly successful one, the Saturn program left its imprint on the institution and its surroundings. During that time, the Center expanded into its own new buildings and, in 1965-1966, reached its peak work force of 7,327 employees and budget of almost $1.7 billion. The rapid physical expansion of the Center was accomplished by an enormous effort to plan, establish, and manage the new facilities. Similarly, the growing work force and increasing complexity of technical activities resulted in a sustaining administrative services and support organization.

As NASA began to procure more technical services, a large support community of aerospace contractors and high-tech industry grew in Research Park and stimulated the local economy. During the Saturn era, the population of Huntsville increased 8-fold from 16,000 in 1950 to 136,000 in 1970. The face of the city changed as new roads, residential areas, civic facilities, a university, and the Alabama Space and Rocket Center opened. That close ties bound the institution and the community was perhaps most evident in the spontaneous public celebrations of the first American satellite launch and the successful landing on the moon; Wernher von Braun, the man who had been so influential in making Marshall and Huntsville the "Home of Saturn," was carried along the streets in triumph, like the coach of a winning team.

For a decade, Marshall's human and physical resources were largely devoted to Saturn work. The institution survived its growing pains, and the practices that proved effective became habitual. A changing organization chart reflected the Center's evolution toward more diverse and complex responsibilities. Many of the Center's lasting strengths are Saturn legacies: its multidisciplinary technical competence, its flair for large-scale systems engineering and systems management, its partnership with industry and universities, its perfectionism expressed in reliable products, and its dedicated work force committed to excellence.

The Saturn program did not quite end with the last Apollo mission in 1972. Saturn vehicles were used to launch four Skylab missions in 1973 and the Apollo-Soyuz mission in 1975. These grand finales launched two new concepts in America's space program: a long-term presence in space for scientific research, and international cooperation in manned spaceflight. On those notes, the Saturn era closed.

During the Saturn-Apollo era, much of Marshall's attention and energy had been

Celebration of the lunar landing downtown Huntsville, July 1969

At the Marshall Center family picnic a few days after the lunar landing

Huntsville-Madison County Public Library photo

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t a Saturn launch

THRUST INTO SPACE

Elation in the launch control center after Apollo II lift-off

President Kennedy greeting employees during 1962 visit to Marshall

Earthrise

focused on one goal, the development of propulsion systems and launch vehicles for the lunar landing program. As the Apollo program waned, the Center made a deliberate and prudent decision to become more diversified. The key event in Marshall's transition from a single project to a multi-project Center was the creation of the Program Development directorate in 1969, under the leadership of today's Center Director, Dr. W. R. Lucas.

At the nucleus of the new directorate were future planners drawn from the laboratories and now charged with responsibility for coordinated long-range planning to conceive new programs for the agency and the Center. This group formed task forces to focus on promising new programs and conducted advanced studies, feasibility studies, preliminary design and program definition. The Program Development directorate rapidly became an effective advocate of Marshall Center capabilities and a "think tank" for original project concepts. Through its efforts, the Center participated in early Space Shuttle concept work that evolved into major assignments for the Shuttle propulsion systems. This group also did the forethought and planning that later culminated in major new space science programs, including the High Energy Astronomy Observatories, Spacelab, and Space Telescope.

The tenure of Dr. Wernher von Braun as Director of the Marshall Center ended in 1970 when he assumed a new position at NASA Headquarters. His long-time associate, Dr. Eberhard Rees, became Director and, until his retirement in 1973, ushered Marshall through a difficult period of reduced funding and manpower. During his term, emphasis at the Center shifted from the Saturn program to Skylab and initial planning for the Space Shuttle. His successor, Dr. Rocco A. Petrone, then presided over the dramatic series of Skylab missions in America's first space station. Since 1974 when Dr. William R. Lucas became Director, the Center has assumed major new responsibilities for the Space Shuttle and other projects.

As the Center looked ahead to the Space Shuttle, it was fully confident that the experience gained in the Saturn program would be well applied to its next assignments. With some changes to meet the technical and managerial challenges of developing new propulsion systems for a new launch vehicle, Marshall Space Flight Center had its blueprint for success.

Dedication of the original Redstone Test Stand at MSFC as a historic site

Huntsville Times photo

**"Houston...
Tranquility Base here.
The Eagle has landed."**

Neil Armstrong, July 20, 1969

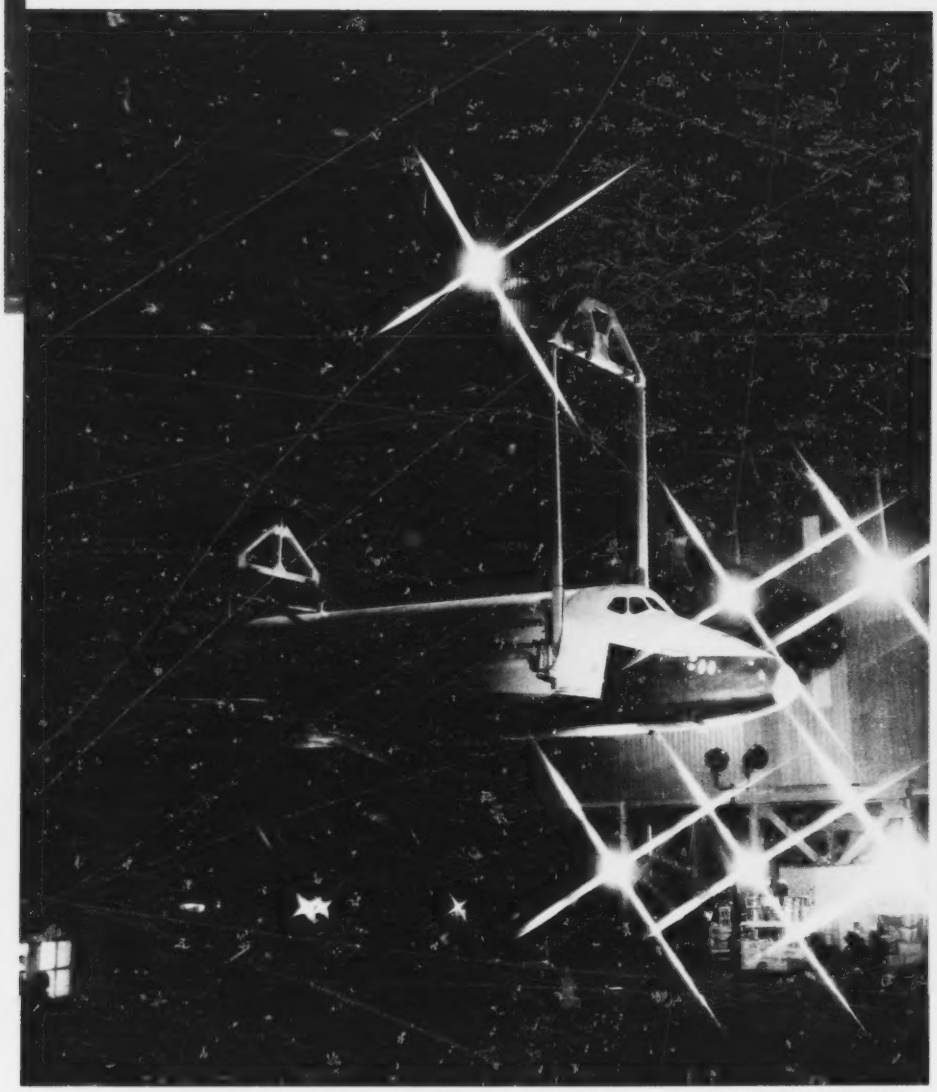
THRUST INTO SPACE

Space Shuttle

Despite the feverish pace of Saturn development and test activities, NASA was already planning a new launch vehicle for the next generation. Impressive and powerful though they were, the Saturns had one disadvantage: they were expendable. Used only once, they were expensive to manufacture, stock in inventory, and use, and the cost per pound of payload delivered into orbit was high. When the agency began looking ahead to a manned space station as the next step beyond lunar exploration, alternatives to expendable rockets were considered. The concept of a reusable Space Shuttle was particularly appealing as an economical vehicle to ferry people and supplies to and from orbit. With its expertise in large launch vehicles and propulsion systems, it was only natural that Marshall Space Flight Center should play a major role in the Space Shuttle program.

By 1970, NASA initiated Space Shuttle development activity. At first, Marshall was heavily involved in the program definition phase leading to the current Shuttle configuration. When the final concept was selected, the Center became responsible for the development of the advanced propulsion systems. Of the principal Shuttle elements – the Orbiter, Main Engines, External Tank, and Solid Rocket Boosters – all but the Orbiter were developed under Marshall Center management.

Much of the Shuttle effort at Marshall was performed by the same personnel and in the same facilities that had served the Saturn program so well. As Saturn activity subsided, these resources were mustered for the Space Shuttle effort. Necessary administrative and physical changes occurred to accommodate the Shuttle program, but in general the Center continued its proven practices in the development of large propulsion systems. Marshall Space Flight Center was well prepared to meet the challenge of developing a new, improved thrust into space.



Readying the Orbiter Enterprise for dynamic tests at Marshall

"You know when you ride a launch vehicle, the future standard launch vehicle of the United States of America, if it doesn't work right, if all those engines don't work right, you don't get very far down range. The Space Shuttle worked perfectly. It was a beautiful thing."

John Young
Commander, STS-1, 1981

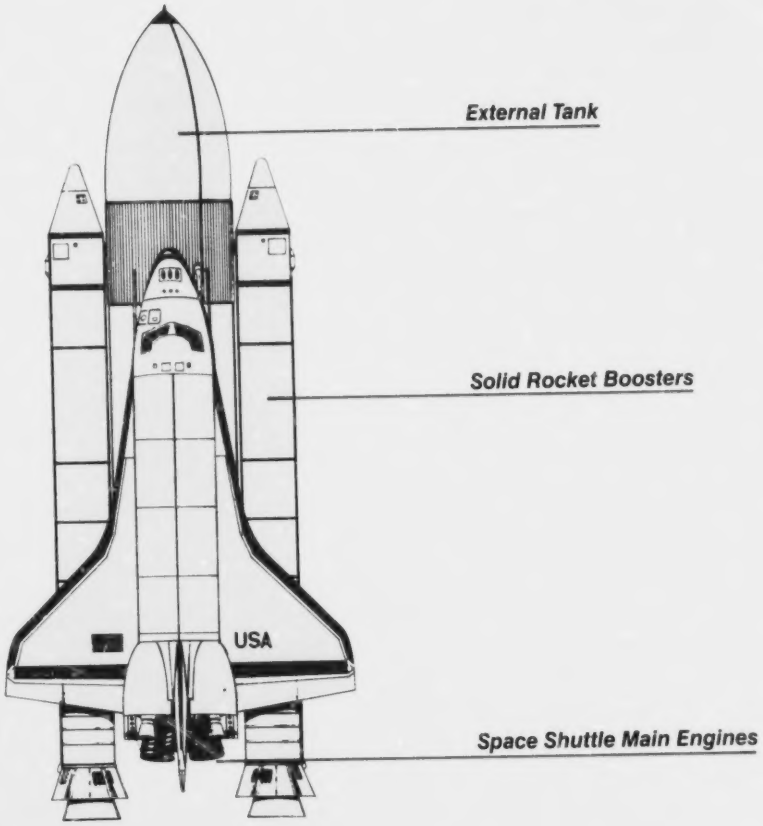
Design Solutions

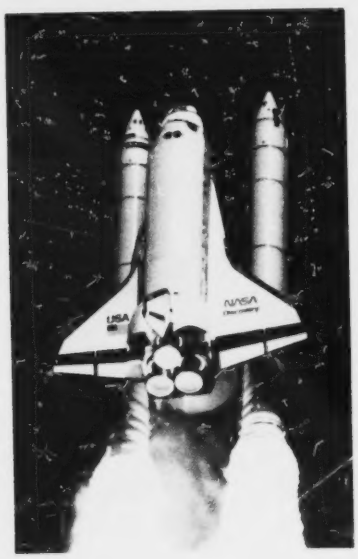
The Shuttle posed a number of technical challenges to Marshall engineers. Serving as both a passenger and cargo vehicle, the Orbiter required highly efficient propulsion systems. How could that capability best be achieved? By integral engines? By external boosters? By a combination of both? How could enough fuel be provided for lift-off without burdening the Orbiter with empty tanks in flight? How could fuel efficiency be improved to get the most energy from every gallon?

For Saturn vehicles, the answer to these questions was expendable booster stages that provided thrust and then were discarded. The Shuttle, however, had to meet a new requirement – reusability – and that introduced a host of new questions. What sort of rocket engine could withstand repeated use? How much of the propulsion system could be recycled and reused on successive flights? What materials could survive the rigors of repeated launches and reentries?

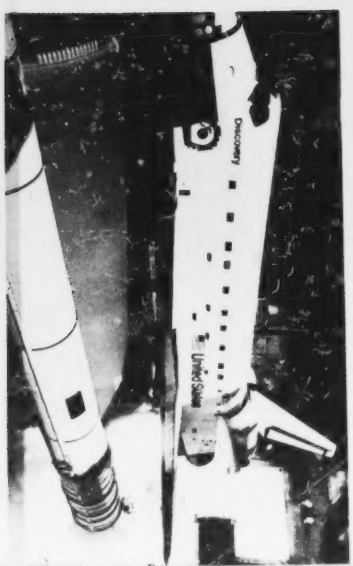
For each of the propulsion elements, the Marshall Center developed unique solutions. The end product was a totally new launch vehicle; its track record to date is just as impressive as that of the Saturns.

The Space Shuttle Main Engines are the most advanced cryogenic liquid-fueled rocket engines ever built. From the outset, it was





Ascent



Lift-off

Landing

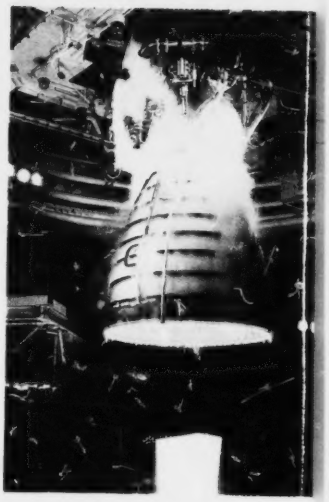
recognized that the Main Engines required the greatest technological advances of any element in the Shuttle program. The three high-pressure engines clustered in the tail of the Orbiter each provide almost a half million pounds of thrust, for a total thrust equal to that of the eight-engine Saturn I first stage. Unlike Saturn engines, the Shuttle Main Engines can be throttled over a range from 65% to 109% of their rated power. Thus, the engine thrust can be adjusted to meet different mission needs. The design goal for each engine is multiple starts and a total firing lifetime of 7½ hours, as compared to the Saturn J-2 engine's lifetime of about 8 minutes. The engines are gimballed so they can be used to steer the Shuttle as well as boost it into orbit.

To get very high performance from an engine compact enough that it would not encumber the Orbiter or diminish its desired payload capability, Marshall worked closely with its prime contractor, the Rocketdyne Division of Rockwell International. The greatest problem was to develop the combustion devices and complex turbomachinery – the pumps, turbines, seals, and bearings – that could contain and deliver propellants to the engines at pressures several times greater than in the Saturn engines. The Shuttle engine components must endure more severe internal environments than any rocket engine ever built. Working out the details of this new high-pressure system was difficult and time-consuming, but the resultant engines represent a significant advance in the state of the art.

The Shuttle Main Engine is the first propulsion system with a computer mounted directly on the engine to control its operation. This digital computer accepts commands from the Orbiter for start preparation, engine start, thrust level changes, and shutdown. The controller also monitors engine operation and can automatically make corrective adjustments or shut down the engine safely. Advances in electronic circuitry were required for the addition of this unit to a rocket engine. Because it operates in a severe environment, special attention was paid to the design and packaging of the electronics during an extensive design verification program.

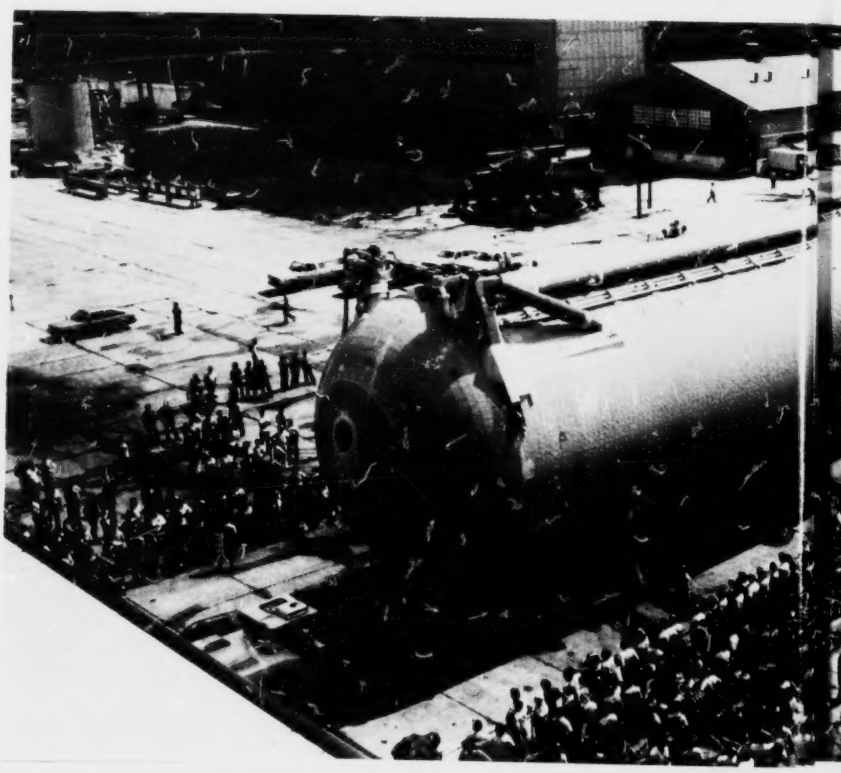
Improved fuel efficiency was achieved by an ingenious staged combustion cycle never before used in rocket engines. In this two-stage process, exhaust gases are recycled for greater combustion efficiency; part of the fuel is combusted in preburners to drive the turbines, after which the exhaust gases are channeled into the main combustion chamber for full combustion at higher temperatures with the balance of the propellants. The rapid mixing of propellants under high pressure is so complete that a 99% combustion efficiency is attained.

Even though they are extremely efficient, the three Main Engines consume a tremendous quantity of propellant, and the tank that feeds them is much larger than the Orbiter itself. Marshall also was responsible for developing the External Tank, a massive container



Test firing of single Space Shuttle Main Engine at National Space Technology Laboratories in Mississippi

Space Shuttle Main Engine – the most advanced liquid-fueled rocket engine ever built.



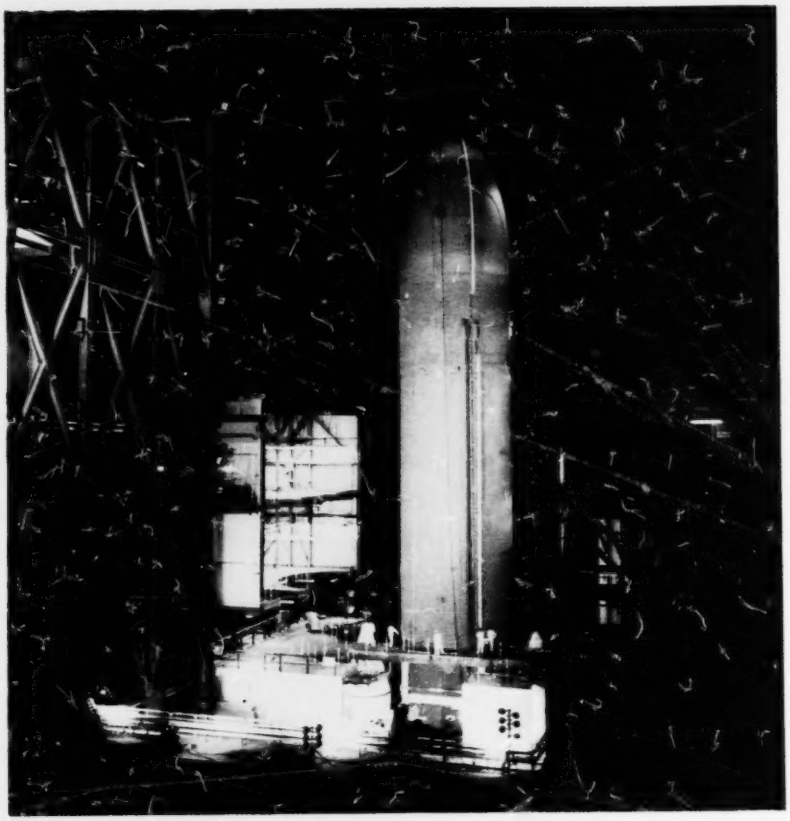
Roll-out of a new External Tank at the Michoud Assembly Facility in Louisiana

almost as tall as the Center's main office building. The External Tank actually contains two tanks, one for liquid hydrogen and one for liquid oxygen, and a plumbing system that supplies propellants to the Main Engines of the Orbiter.

The External Tank presented a variety of technical problems, both as a fuel tank and as the structural backbone of the entire Shuttle assembly. Standing 154 feet tall with a 27-foot diameter, the External Tank is a towering structure; fully loaded, it contains more than a half million gallons of propellant and weighs more than one and a half million pounds. Marshall personnel worked closely with the prime contractor, the Martin Marietta Corporation, to devise appropriate design solutions for its unusual requirements.

The Center's prior experience on the Saturn V second stage was directly applicable to the cryogenic propellant design requirements of the External Tank. To maintain the extremely low temperature necessary for the liquid hydrogen, the exterior skin of the tank was covered with about an inch of epoxy spray-on foam insulation. This thermal wall reduces heat into the tank and also reduces frost and ice formation on the tank after propellants are loaded. The tank is further protected in critical areas from the severe aerodynamic heating during flight by a localized ablative undercoat that dissipates heat as it chars away.

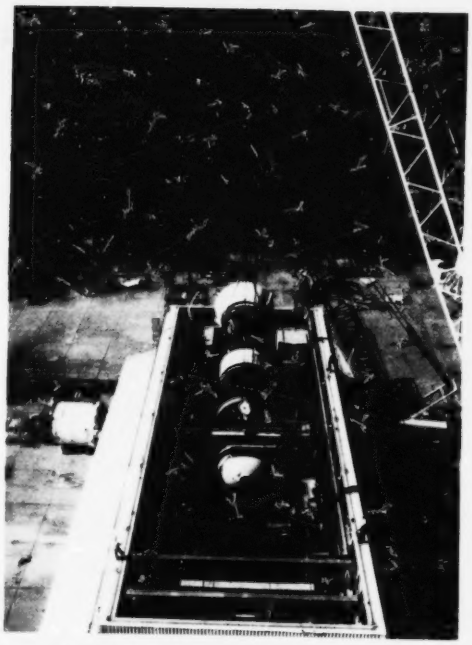
Structurally, the External Tank is attached to the Orbiter and the Solid Rocket Boosters. The load-bearing function, both on the launch pad and during liftoff and ascent, was a major design driver. Engineers devised several solutions to make the tank as strong and as lightweight as possible. The aluminum alloy structure was designed to handle complex loads, and the problem of propellant sloshing in the tanks was solved with baffles to avoid instabilities that could affect the Shuttle's flight.



Preparing to mate the External Tank and Solid Rocket Boosters at Kennedy Space Center, Florida

Another important design consideration was the fact that the External Tank is not reusable. Therefore, its design must be simple and its cost minimal. Solutions to these requirements included locating the fluid controls and valves in the Orbiter and drawing power for the electronics and instrumentation from the Orbiter. With these economies, expendable hardware has been minimized.

The External Tank is manufactured at the Michoud Assembly Facility by Martin Marietta under Marshall Center management. New tooling, such as a welding fixture half the span of a football field, was required to handle production of the huge tank. Eventually, production of 24 tanks per year is planned. The barge transportation system developed to deliver Saturn stages is now used to transport External Tanks to the launch sites.

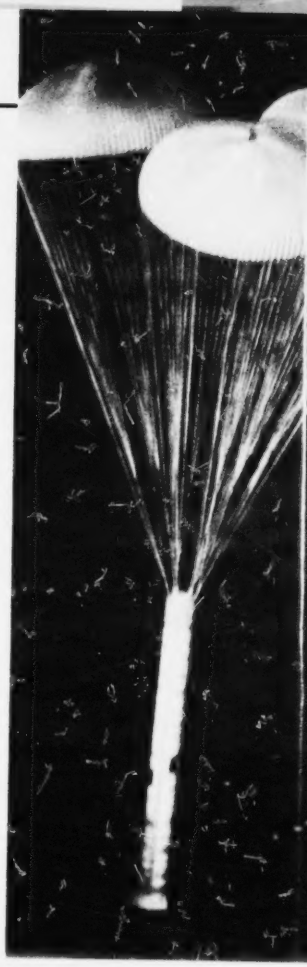


Lowering Solid Rocket Booster into MSFC structural test stand

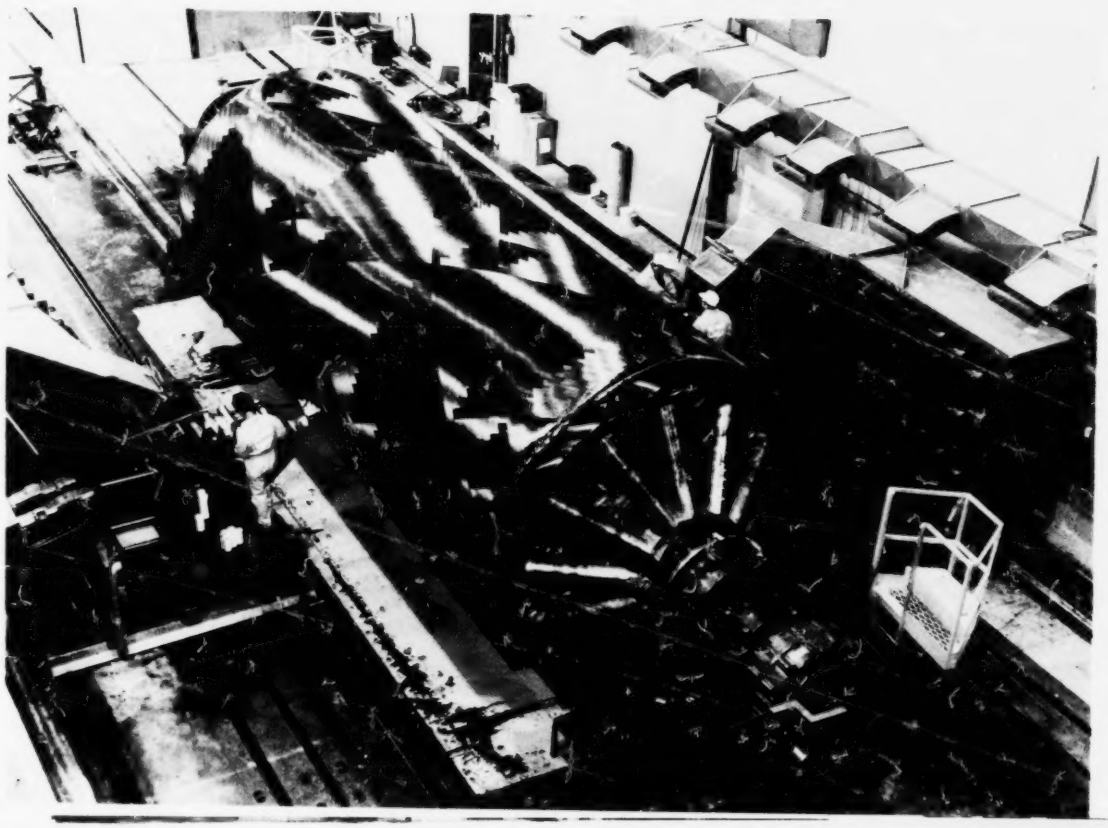
The Solid Rocket Boosters are the first solid propellant rockets built for a manned space vehicle and the largest solid rockets ever flown. Burning for approximately two mi: utes, each booster produces almost three m.. lion pounds of thrust to augment the Shuttle's main propulsion system during liftoff. The boosters also help to steer the Shuttle during the critical first phase of ascent. The 11-ton booster rocket nozzle is the largest movable nozzle ever used. The Solid Rocket Boosters were designed as an in-house Marshall Center project, with United Space Boosters as the assembly and refurbishment contractor. The Solid Rocket Motor is provided by the Morton Thiokol Corporation.

The Solid Rocket Boosters are deceptively simple in appearance, considering their various functions. On the launch pad, the boosters support the entire Shuttle assembly. In flight, they provide six million pounds of thrust and respond to the Orbiter's guidance and control computer to maintain the Shuttle's course. At burnout, the boosters separate from the External Tank and drop by parachute to the ocean for recovery and subsequent refurbishment.

The major design drivers for the Solid Rocket Boosters were high thrust and reuse. The desired thrust was achieved by using state-of-the-art solid propellant and by using a long cylindrical motor with a specific core



Descent of spent Solid Rocket Booster for recovery and reuse



Newly developed filament-wound motor case for Solid Rocket Booster segments

design that allows the propellant to burn in a carefully controlled manner.

The requirement for reusability dictated durable materials and construction, which led to several innovations. Paints, coatings, and sealants were extensively tested and applied to surfaces of the booster structure to preclude corrosion of the hardware exposed to the harsh seawater environment. Specifications called for motor case segments that could be used 20 times. To achieve this durability, engineers selected a weld-free case formed by a continuous flow-forming process. Machining and heat treatment of the massive motor case segments also were major technical efforts.

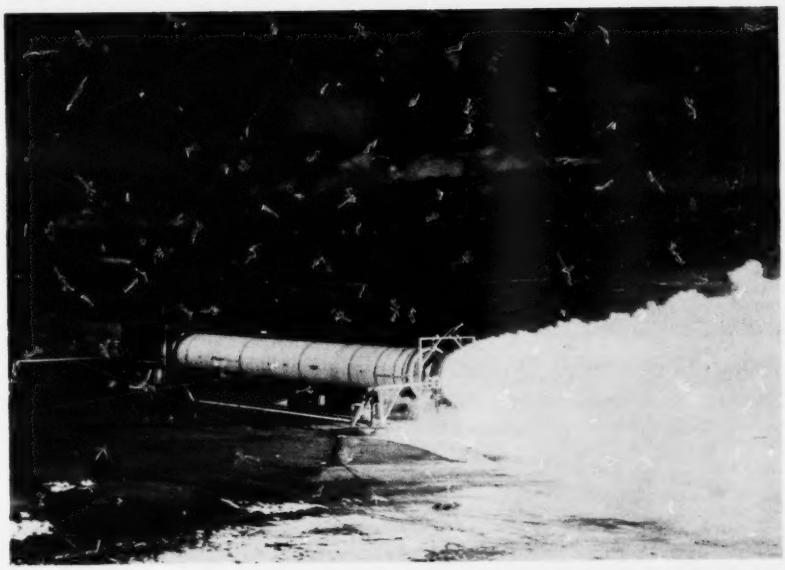
Reusability also meant making provisions for retrieval and refurbishment. The boosters contain a complete recovery subsystem that includes parachutes, beacons, lights, and tow fixtures. The 136-foot diameter main parachutes are the largest ribbon parachutes ever used in an operational system, and the Solid Rocket Boosters are the largest objects ever recovered by parachute. The boosters are designed to survive water impact at almost 60 miles per hour and maintain flotation with minimal damage.

Besides fulfilling its primary responsibilities for propulsion systems, Marshall supported many other efforts in Shuttle systems engineering and analysis. The Center's technical competence in materials science, thermal engineering, structural dynamics, aerodynamics, guidance and navigation, orbital mechanics, systems testing, and systems integration all proved valuable to the overall Shuttle development program. Rigorous testing and a score of successful launches attest to the design achievement of the Shuttle propulsion systems.

Shuttle Testing

Shuttle test activities were a major responsibility of the Marshall Space Flight Center for several years in the late 1970's. Both in Huntsville and at the related NASA facilities in Louisiana and Mississippi, as well as at contractor sites around the country, Marshall personnel participated in many development and qualification tests. Whether they worked with individual components within a laboratory or participated in engine static firings or dynamic tests of the mated Shuttle elements, these people held to the standard of excellence necessary for a successful Shuttle program. Long before the first Shuttle launch on April 12, 1981, Marshall had built confidence in the propulsion systems.

Solid Rocket Booster – the largest solid rocket motor ever flown and the first designed for reuse.



Test firing of Solid Rocket Motor at Morton Thiokol facility in Utah

Preparing for and coordinating the many different test programs was a significant technical challenge. Rather than build new test facilities for the massive Shuttle elements, Marshall modified existing resources. Test fixtures and equipment that had stood idle since the Saturn era were revived and remodeled to support various Shuttle test efforts. In addition, special new equipment was constructed.

The busiest year was 1978, when the External Tank structural and vibration tests, the Solid Rocket Booster structural tests, and the Mated Vertical Ground Vibration Tests were done in Huntsville by Marshall Center employees. Meanwhile, single engine tests and main propulsion system cluster firings were in progress at the National Space Technology Laboratories (formerly Marshall's Mississippi Test Facility). Solid Rocket Motor tests were underway in Utah, and subsystems tests, such as checkout of the booster parachutes, were being completed elsewhere. Marshall played a prominent role in the year-

Arrival of Enterprise at Marshall for year-long test series

Congressman Ronnie Flippo touring Marshall during Shuttle test period

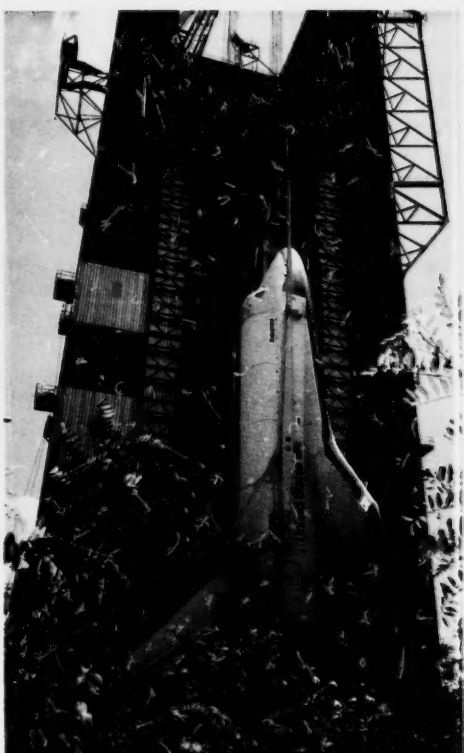
The Space Shuttle – a launch vehicle, cargo carrier, service station, research lab, and home in space.

long Mated Vertical Ground Vibration Test program, the critical evaluation of the entire Shuttle complement – Orbiter, Tank, and Boosters – assembled for the first time. The phased test sequence began in March of 1978 when the Orbiter Enterprise arrived at Marshall and was greeted by throngs of employees and citizens. The Orbiter was hoisted into the modified Dynamic Test Stand originally built for Saturn V testing, mated first to an External Tank, and subjected to vibration frequencies comparable to those expected during launch and ascent. Several months later, the Solid Rocket Boosters were added for tests of the entire Shuttle assembly. The test series confirmed the structural interfaces and mating of the entire Shuttle system and allowed mathematical models used to predict the Shuttle's response to vibrations in flight to be adjusted so that effects for future flight environments could be predicted adequately prior to launch. Marshall managed and conducted this important test program with support from the Shuttle contractors.

Concurrently, both the External Tank and the Solid Rocket Boosters underwent independent structural tests. These activities occurred in Marshall's test stands and in the Building 4619 test facility, all formerly used to test Saturn stages. In addition, captive firings of a 6.4% scale model Shuttle enabled engineers to determine the launch acoustic environment and its effects on both the vehicle and the launch pad at Kennedy Space Center.

ABOVE: ***MSFC test control engineer putting Shuttle elements through vibration tests***

RIGHT: ***Preparation for Mated Vertical Ground Vibration Tests***



Scale model firings also influenced launch pad design criteria for the new western launch site at Vandenberg Air Force Base in California.

Marshall's other principal test responsibility was for the Main Engine development. Engines were fired repeatedly during their development and later for flight qualification. The highlight of propulsion system testing was the Main Propulsion Test series of cluster firings, in which three engines were mounted to an Orbiter mockup and fired simultaneously while drawing propellants from an actual External Tank. These tests, which began in 1977, verified not only the operational compatibility of the main propulsion system elements but also propellant loading procedures and propellant feed systems. In addition, Marshall established an in-house laboratory to test and verify the avionics and software system of the Main Engines through simulations of all operating conditions.

From earliest development through actual flights, major elements of the Shuttle have been, and continue to be, tested under Marshall Center supervision. These test programs ensure the safe, reliable performance of the nation's Space Transportation System. Rigorous testing has always been a hallmark of Marshall's commitment to excellence.

Another in a long series of successful Space Shuttle launches

Shuttle Operations

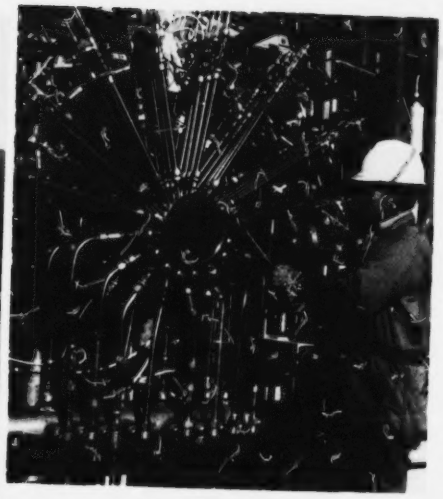
The Center's responsibilities for Space Shuttle Systems extended beyond the development phase into the operational era. Marshall personnel are involved in two ongoing Shuttle efforts: launch support and production. (An additional major activity, the development and management of scientific payloads for Shuttle flights, is treated elsewhere in this text.)

The Huntsville Operations Support Center (HOSC) in Building 4663 is a hub of activity during propellant loading, countdown, launch, and powered flight toward orbit. This facility has evolved considerably from the simpler Saturn era operations room and now is capable of secured operations to support Department of Defense missions. From the HOSC, Marshall personnel monitor the status of the propulsion systems; via a sophisticated communications network, they receive data from sensors aboard the Shuttle and from Marshall management teams at the launch site. HOSC duty entails around-the-clock work to guarantee a trouble-free launch on schedule. Evaluation of flight data is a crucial activity not only for launch support but also to assure that follow-on flights can be safely made.

Marshall is responsible for the continued production of External Tanks at the Michoud Assembly Facility. To manage its manufacturing enterprise, the Center engages in production planning, readiness reviews, and technology improvements on the production and assembly lines to reduce costs. Marshall is meeting the new challenge of mass producing high-quality hardware and doing it on schedule and with decreasing costs.

After a mission, the Solid Rocket Boosters are recovered and refurbished. Postflight activities include engineering assessments of the wear-and-tear on the hardware and necessary repairs. Marshall engineers have devised techniques to diminish impact damage to the boosters and to streamline refurbishment operations for fast turn-around between missions.

Engineers on duty in the HOSC during Space Shuttle missions



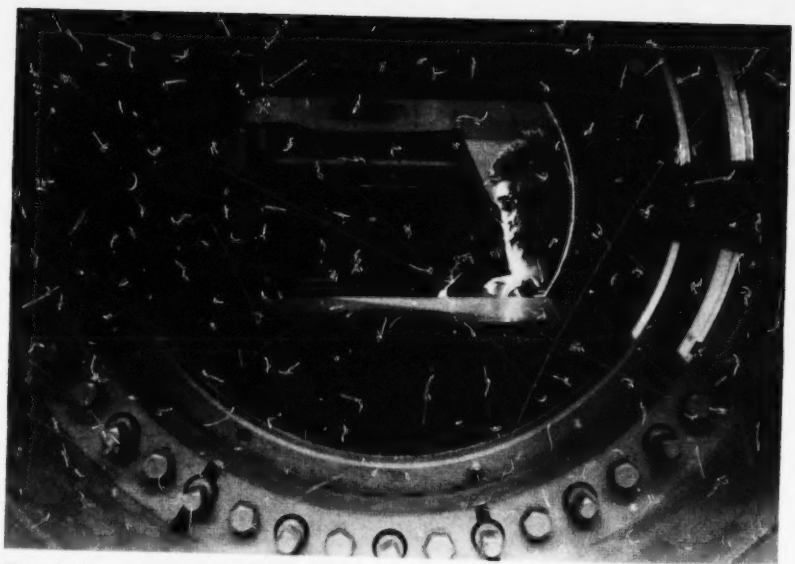
Ongoing engine research and technology development at Marshall

Shuttle Improvements

Shuttle responsibilities did not end with development of operational Main Engines, External Tanks, and Solid Rocket Boosters. Instead, Marshall is engaged in ongoing technology advancement to improve the Shuttle propulsion systems at reduced costs. In various laboratories around the Center, engineering evaluations of Shuttle performance continue as Marshall's experts investigate ways to make a proven product less costly.

The two primary challenges are to increase the Shuttle's payload-carrying capability and to improve the Shuttle's performance. To meet the first challenge, Marshall engaged in a weight-reduction campaign to trim pounds from propulsion elements in order to carry heavier payloads into orbit. A lightweight External Tank was developed by removing some insulation, trimming material from some structural elements, and using stronger materials where possible; this tank is already in use. The Center also developed lighter weight steel motor cases for the Solid Rocket Boosters and an innovative filament-wound case that is even lighter and stronger. For improved economics and performance, Marshall is also managing the development of a Main Engine with a longer flight lifetime.

The design of Shuttle propulsion elements continues to be refined through Marshall's ongoing flight certification program; many of the improvements have been installed and are now in use. The continuing advancement of Shuttle technology is as important and challenging as the original design and development efforts.



Shuttle improvements studied in Marshall's engineering laboratories

Shuttle Legacies

In 1981, Marshall and the nation once again watched expectantly as a new launch vehicle, the Space Shuttle, rose from the pad. This successful first flight with the Orbiter Columbia introduced the era of the Space Transportation System and a continuing series of Shuttle missions. Three other Orbiters – Challenger, Discovery, and Atlantis – soon joined the fleet, and Americans felt new pride in the triumphs of the space program.

The Shuttle development effort evolved naturally out of the Saturn experience in large launch vehicles and propulsion systems. Marshall continued its close working relationship with contractors and maintained its strong technical competence in the relevant engineering disciplines. The Center also continued its successful managerial practices. However, certain changes in NASA's philosophy and resources challenged Marshall in new ways. During the Shuttle period, Marshall Space Flight Center became a leaner, stronger institution as it adapted to these changes.

The principal philosophical change was the necessity of reuse. In a time of declining budgets and increased awareness of limited resources, reusability was a high priority. Marshall met the technical challenge of developing durable space hardware that could be recycled for many missions. Despite delays along the way, the Shuttle development program proceeded successfully.

The achievement was especially noteworthy because the Center also was tasked with the administrative challenge of reassigning facilities and personnel. As Saturn work tapered off and Marshall became involved in other projects, the Center had to reallocate many of its resources. Major reorganization occurred as leadership passed from Dr. von Braun in 1970 to three successors in four years. From 1965, the peak year of Saturn activity, to the first year of Shuttle activity in 1970, Marshall lost almost 20% of its civil service work force as federal budget cuts slashed the Center's funding in half. This trend continued well into the 1970's until the budget and

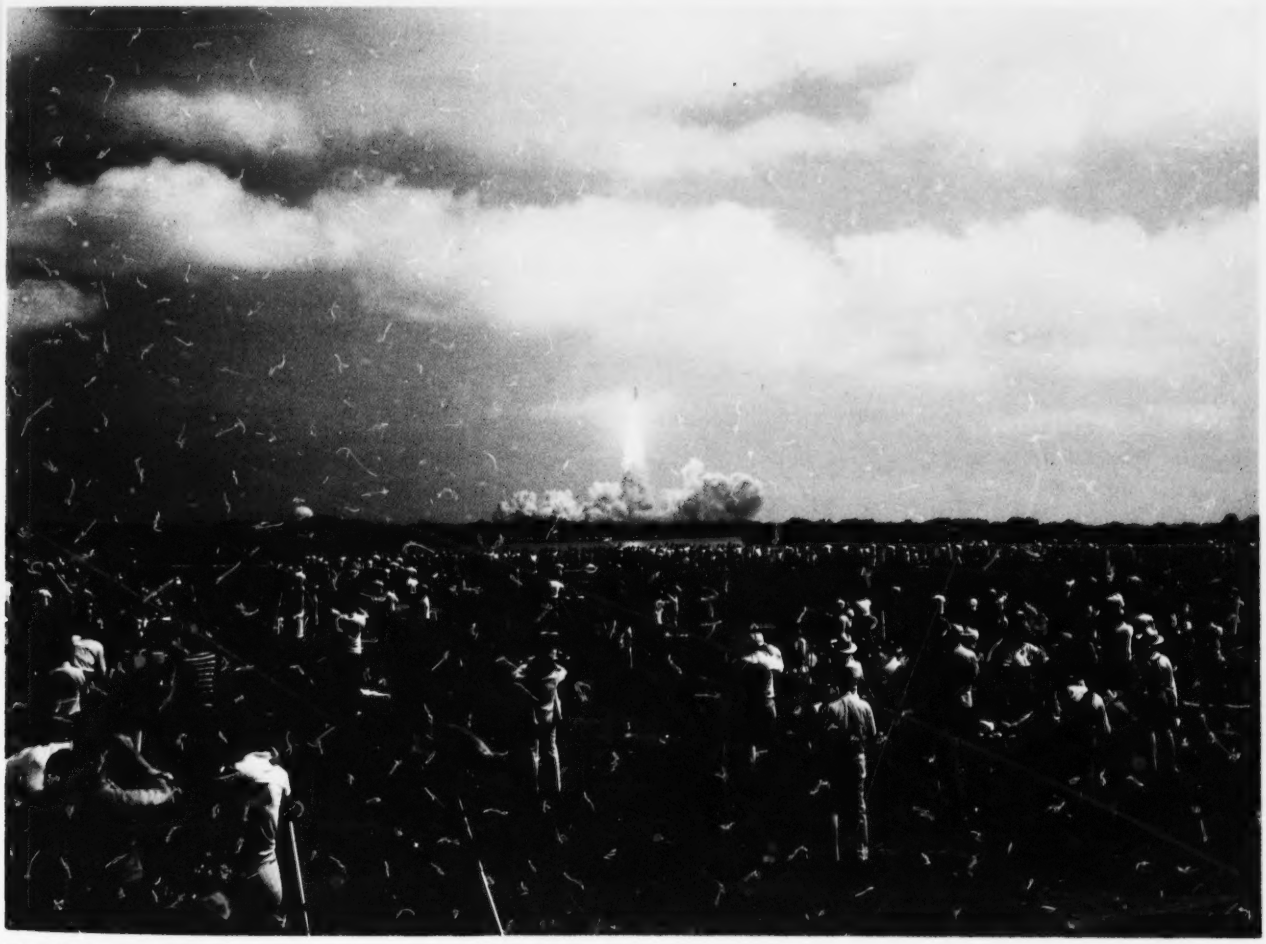
The Space Shuttle markedly expands man's ability to do things in space at lower cost, more often, and more effectively than ever before.

staffing levels stabilized with staff at approximately 60% of the peak Saturn year.

Dr. W. R. Lucas, who became Center Director in 1974, remarked that Marshall had survived its years of crisis with its commitment to excellence intact. The Center managed to cope with the reductions and still tackle very ambitious projects.

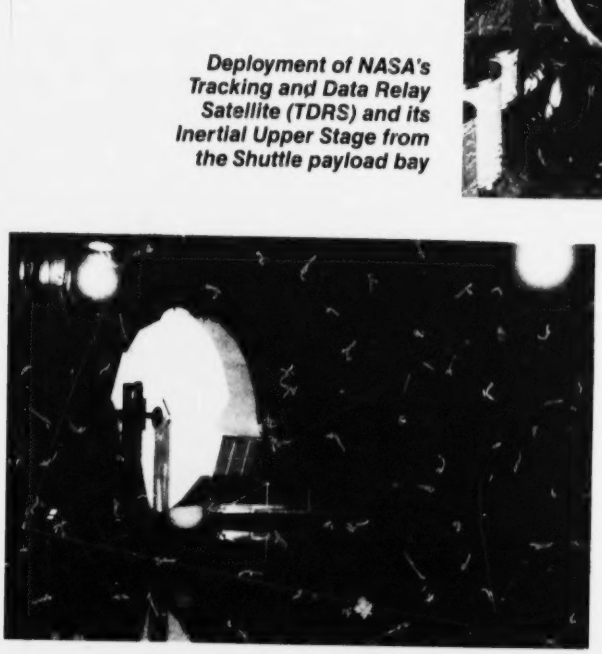
Meanwhile, the Shuttle endeavor influenced the Center's work in space science and manned orbital systems. Development of a vehicle capable of routine access to space opened many possibilities for using space as a laboratory and work place. The Center's development activity in flight experiments, observatories, and basic research and technology accelerated noticeably during this period. Marshall also devoted considerable attention to manned space activity – servicing spacecraft, assembling large structures, doing experiments – made possible by the Shuttle.

A work place and delivery vehicle in orbit

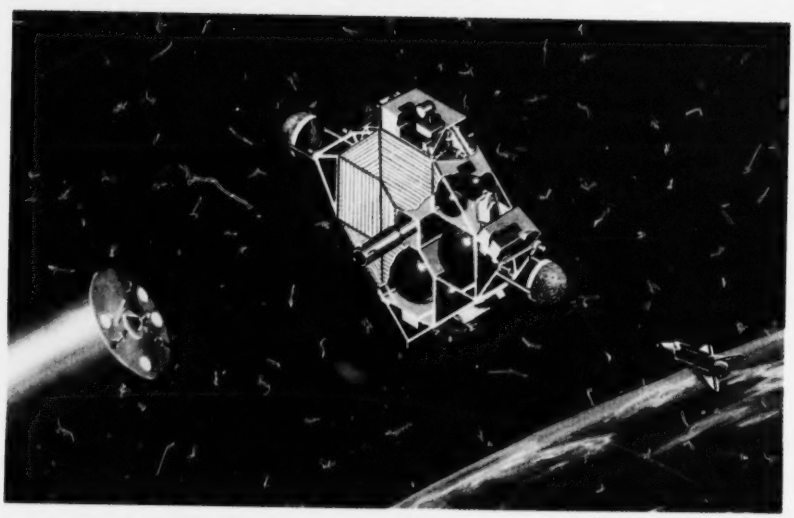


Twentieth-century pilgrimage

Deployment of NASA's Tracking and Data Relay Satellite (TDRS) and its Inertial Upper Stage from the Shuttle payload bay



OMV simulator in MSFC's teleoperation and robotics research laboratory



Concept for an Orbital Maneuvering Vehicle to ferry payloads to and from the Shuttle in low-Earth orbit

Advanced Transportation Systems

In 1977, Marshall acquired responsibilities for another propulsion element, an upper stage to boost payloads to higher orbits or to send spacecraft on interplanetary voyages. While the Air Force had primary responsibility for development of an Inertial Upper Stage, Marshall became NASA's management and coordination center, providing the agency's design and operational requirements to the Air Force and participating in the development of two upper stage configurations for NASA missions. Marshall participated in key design reviews, interface working groups, and test activities for the NASA upper stage configurations.

NASA's first use of the upper stage to launch a Tracking and Data Relay Satellite in 1983 was only a partial success; the satellite did not reach the desired orbit and further launches were delayed pending evaluation and modification of the boosters. The upper stage subsequently performed satisfactorily on a mission in 1985.

The Center also became involved in two commercial ventures for upper stages. For Shuttle missions, Marshall monitors the Payload Assist Module developed independently by McDonnell Douglas. A larger Transfer Orbit Stage under development by the Orbital Sciences Corporation is also being monitored by Marshall. These upper stages broaden the variety of payloads that can be placed in orbit from the Shuttle.

What kinds of cargo carriers and people movers are needed in the Space Station era? As commercial activity in space increases with people living and working there, the demand for transportation service will multiply. Planning and concept studies are well under way at Marshall Space Flight Center to forecast the space transportation needs of the future and to develop appropriate vehicles.

In the future, different vehicles will be needed for travel between the ground, low orbit, high orbit, and beyond. In general, Marshall planners foresee three new classes of vehicles to satisfy different mission requirements: Orbital Maneuvering Vehicles, Orbital Transfer Vehicles, and advanced large-lift vehicles. These new vehicles will augment the capabilities of the proven Space Shuttle, which will continue to offer routine passenger and cargo service between the ground and low-Earth orbit.

The idea of an Orbital Maneuvering Vehicle, a space "tug," has been considered at the Center for several years. In 1977, Marshall was authorized to define a Teleoperator

Retrieval System, a remotely controlled propulsive vehicle that could rendezvous with an orbiting spacecraft, grapple it, and move it elsewhere. Originally conceived for future on-orbit servicing missions, the teleoperator was considered for use in a possible Skylab rescue attempt. Development activity accelerated to meet a pressing schedule as Skylab's orbit decayed more rapidly than anticipated.

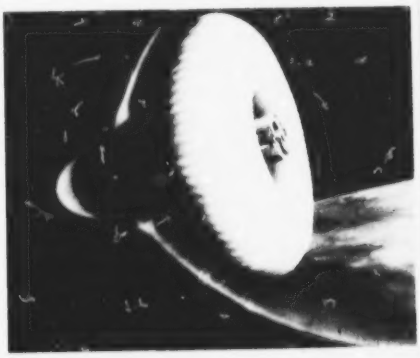
Work on the Teleoperator Retrieval System progressed through rendezvous and docking simulations as Marshall investigated suitable hardware fixtures and remote control procedures. The Center also engaged in a number of studies to determine the visual and manipulator aids needed for remote operations; television systems, hand controls, and end effectors received careful attention. Although the Skylab reboost/deboost mission did not occur, the planning activity energized teleoperator research and technology at the Center. The capability for orbital docking simulation was expanded to include a unique six degree-of-freedom motion system for evaluation of docking mechanisms.

The Orbital Maneuvering Vehicle now under study is an improved version of this space tug with a larger service role than originally foreseen. In addition to satellite retrieval and delivery tasks, this vehicle might perform remote maintenance, assembly, and logistics tasks to service free-flying spacecraft and also support Space Station activities.

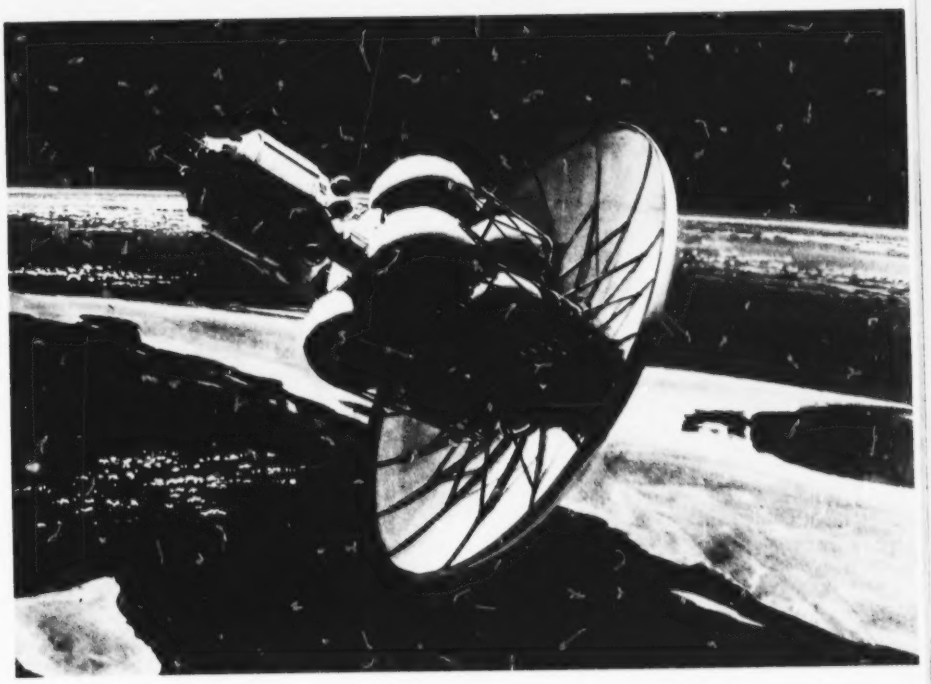
Marshall Space Flight Center has been a pioneer in advanced teleoperation and robotics technology research for more than a decade. The Center is continuing this research in a new evaluation laboratory opened in 1984. This unique facility houses a 4,000 square foot precision flat floor and air bearing vehicles; it is used as a test bed for remotely controlled vehicles. Simulations in the facility serve to evaluate remote systems concepts and also to train operators. The laboratory will play a prominent role as an Orbital Maneuvering Vehicle simulator.

Orbital Transfer Vehicles are required to deliver some orbital payloads, including people, to higher altitudes beyond the Shuttle's range, which is limited to about 600 miles, and to launch interplanetary probes from Earth orbit. They also can be used to ferry spacecraft between stationary geosynchronous orbit at 22,000 miles and the Space Station in low-Earth orbit for servicing or refurbishment, or they can be used to carry work crews to service distant satellites.

Over the years, Marshall engineers have considered various concepts for advanced transportation systems to meet these needs for greater payload capability. Among the most promising were a Spinning Solid Upper Stage for deliveries to geosynchronous orbit and a Solar Electric Propulsion Stage that generated and used its own power. The Center is now investigating several concepts for aeroassisted braking that would enable a returning Orbital Transfer Vehicle to slow its speed without relying on an engine. Although no particular hardware configuration has yet been selected, the



Concepts for Orbital Transfer Vehicles to ferry payloads, supplies, and astronauts between low-Earth and geosynchronous orbits



"We will undoubtedly continue to explore nearer space. We will keep going to the moon, maybe one day build a permanent camp on the moon, and then go on to Mars and Venus."

Dr. Wernher von Braun, 1967

THRUST INTO SPACE

planning studies draw upon Marshall's resident propulsion and vehicle design talents.

The Center has also given much attention to complementary launch vehicles derived from the basic Space Shuttle propulsion elements. These may serve as logistical supply vehicles to carry needed materials and equipment into orbit. The challenge in this effort is to adapt existing designs for missions requiring vastly greater payload lift, perhaps a million pounds of payload as compared to the Shuttle's 65,000 pound capability. Various combinations of modified engines, tanks, and boosters are being considered. Although no specific concept has been authorized for development yet, the thrust of these studies is to augment the capabilities of the Shuttle for unmanned delivery of payloads and for launch of extremely heavy cargo.

A Glimpse of the Future

Very soon, space will be a busy work place. Traffic will increase noticeably as people, materials, and equipment are routinely transported back and forth between the ground and low-Earth orbit. Traffic will also begin to flow to and from more distant regions of space – geosynchronous orbit, the moon, the neighboring planets. Talk of manned lunar colonies or a manned expedition to Mars is no more idle today than talk of a Space Station was 15 years ago. Now the Space Station is becoming a reality; what about the other dreams?

Sophisticated as it is, the current Space Shuttle is but the first generation model. It alone cannot meet all the transportation needs of the future. New vehicle models are yet to be designed and developed. Like automobiles, they will progressively become more efficient, more comfortable, more serviceable.

Consider how rapidly propulsion systems and launch vehicles have evolved. It took only a decade to develop and prove the transportation system that safely carried people to the moon and back. In another decade, a reusable space vehicle was in service. What was once inconceivable – spaceflight – is now taken for granted.

Although it is now possible to send people back and forth, to place satellites in desired orbits, to deploy and retrieve payloads, these achievements are rudimentary compared to what can be done. Despite the advances of recent years, technology has not yet approached the limits of what is theoretically possible.

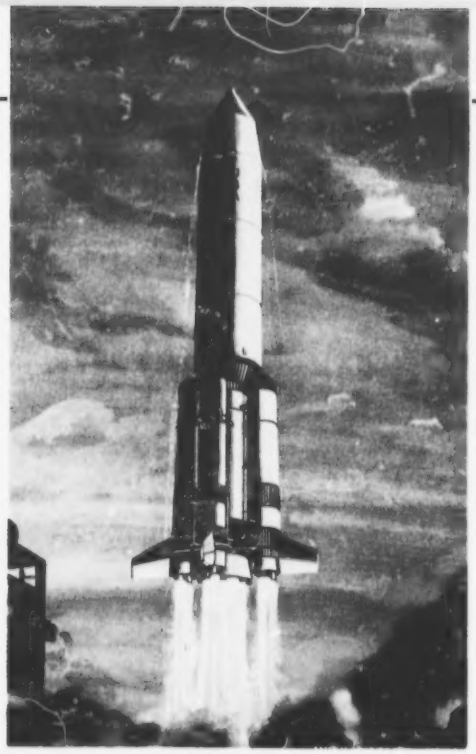
Marshall is NASA's primary Center for propulsion systems development, and many of the test facilities here are unmatched. Marshall also has unique facilities for the development of large structural systems and impressive laboratory resources in the various engineering disciplines. The necessary tools are available here to meet the challenges of future space transportation systems.

Marshall people can and will make new strides in the technologies for advanced propulsion systems and launch vehicles. Whereas the first quarter-century results were the Saturns and the Shuttle, in the next quarter Marshall may produce a fleet of quite different vehicles – towering ones for heavy-lift launches, agile ones for orbital maneuvering, powerful but lightweight ones for orbit transfers, vehicles that run on exotic fuels or novel engines, robotic vehicles, perhaps even compact models for manned use. The possibilities are exciting and unlimited.

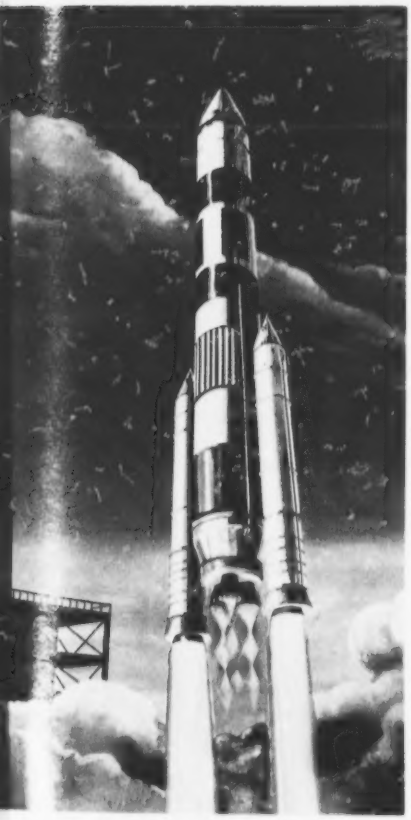
As it looks toward future transportation in space, Marshall is exploiting its wealth of experience and imagination. Drawing upon the technical expertise of its staff in all the engineering disciplines, this Center expects the thrust into space to remain one of its primary occupations and achievements in the years ahead. ■

Side-mount Shuttle-Derived Vehicle

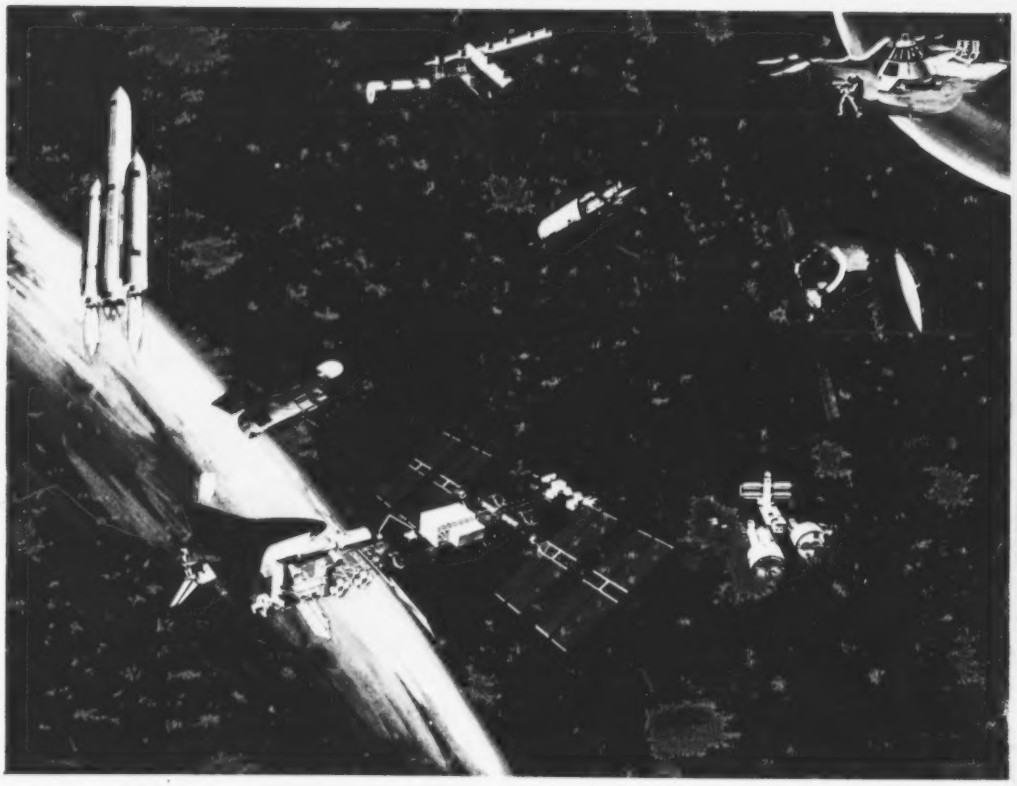
"You and I have been privileged to live and participate in a unique period in man's history, a period of explosive technological advancement that has been unequaled in any other epoch."
Dr. W. R. Lucas



Concept for new Heavy-Lift Launch Vehicle



In-line Shuttle-Derived Vehicle



Propulsion and transportation for the future: a high priority at Marshall

RESEARCH ON THE NEW F

SPACE SCIENCE

FRONTIER: Why

hy do we launch vehicles and people into space? What is the purpose of space flight? From a scientific point of view, the answer is that we can do research in space that is impossible on Earth. There we have a global view of our planet for atmospheric and geophysical observations, an unobstructed view of the heavens for astronomical observations, a microgravity environment for experiments in life sciences and materials science, and direct exposure to the radiation and vacuum of space. Thus, space is a unique laboratory. NASA's charter explicitly states that "activities in space should be devoted to peaceful purposes for the benefit of all mankind." Space science research extends the frontiers of knowledge in accordance with that charter.

Even while they were affiliated with military projects, the early rocket pioneers considered the potential uses of rockets for scientific research in space. It seemed quite practical to replace missile warheads with scientific experiments or to develop more powerful vehicles to place satellites, laboratories, and people into space. Dr. Wernher von Braun remarked that the driving ambition of his colleagues had been to engineer rockets for scientific research. With a singleness of purpose, they were dedicated to the evolution of space flight for the exploration of the universe.

The Marshall Center's involvement in space science can be traced to the launch of America's first satellite, Explorer I in 1958, aboard the Jupiter C rocket developed in Huntsville by von Braun's group and the Army. The scientific return was immediate and startling: discovery of the Van Allen radiation belts encircling Earth. Shortly thereafter, the

"I am convinced that man's inevitable march toward knowledge is now over the very earliest hurdles *only*, and the vastness of the unknown still before us is limitless."

Dr. Wernher von Braun, 1958

RESEARCH ON THE NEW FRONTIER

Huntsville group launched a Pioneer satellite on a solar expedition and placed another Explorer into orbit. Although some of the Explorer and Pioneer satellites were developed elsewhere, the rocket group's appetite for space science was whetted by participating in the flight experiments. Soon they began to find opportunities for scientific experiments and payloads on rocket test flights, and they began to plan future missions dedicated to science. Scientists involved with the launch team eventually became the nucleus of Marshall's Space Science Laboratory.

Over the first quarter-century of its history, space science research has evolved into a significant mission at Marshall Space Flight Center. The Center's staff includes distinguished scientists in the disciplines of astronomy and astrophysics, atmospheric physics, solar and magnetospheric physics, and materials science. They have made important contributions to knowledge through work not only in the laboratories here but also in the vast natural laboratory of space. Combining their talents with Marshall's engineering and managerial resources, they have developed sophisticated space observatories as well as a host of smaller flight experiments and payloads. Furthermore, research at the Center is extending the frontiers of knowledge in several fields of science and technology.

The Marshall Center's achievements in space science are sometimes overshadowed by the size and spectacle of its achievements in launch vehicle engineering. Yet, the institution also has a rich scientific heritage. Marshall scientists are steadily seeking to solve the mysteries of the universe. In the quest for knowledge, they are committed to excellence.

The Marshall Center's first satellite, Pegasus

Small Scientific Payloads

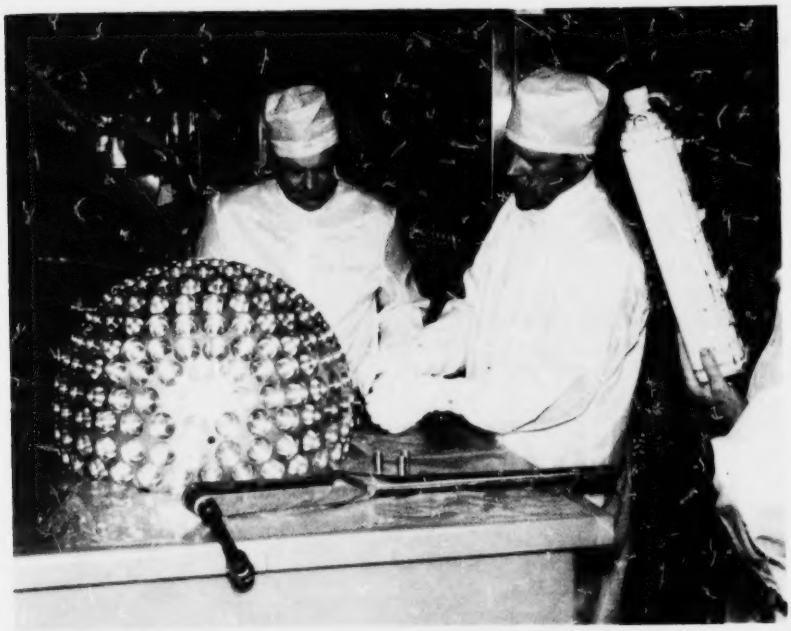
The impetus for the large Saturn booster was the exploration of space. During its development, Marshall had several opportunities to use the Saturn for research payloads. The Center also developed some small satellites that were launched by other vehicles.

As a bonus on two of the early Saturn engineering test flights in 1962, the dummy upper stages were used for a scientific experiment called Project Highwater. Thousands of gallons of ballast water from the inert stages were released into the upper atmosphere. This effort to investigate the effects of water clouds marked the first use of a Saturn vehicle for scientific purposes, even though the research was clearly secondary to the engineering objectives of the flights.

The first genuine scientific payloads launched by Saturn vehicles, and the first satellites for which the Marshall Space Flight Center had full responsibility, were the three Pegasus micrometeoroid detection satellites orbited in 1965. The purpose of the Pegasus project was to collect information about the abundance of potentially hazardous micrometeoroids at high altitudes, where the manned Apollo missions would orbit. Spacecraft designers were keenly interested in the information, because the vehicle and crew were in jeopardy if tiny particles could puncture a spacecraft skin.

As project manager, the Marshall Center was responsible for the design, production, and operation of the satellites and for data analysis. Working with the satellite contractor, Fairchild, Marshall personnel built up valuable experience in the design and operation of scientific payloads, particularly in sensor technology, satellite stabilization, thermal control, and data transmission. Micrometeoroid detectors and sample protective shields of varying thickness were mounted on the satellite's wing-like solar cell arrays. The sensors successfully measured the frequency, size, direction, and penetration of scores of micrometeoroid impacts.

Marshall's first major venture in space science research paid handsomely. Micrometeoroid penetration data collected by the Pegasus satellites and telemetered to the ground were used by spacecraft engineers to confirm Saturn-Apollo and other designs. Pegasus results also influenced thermal coating technology and gave insight into the expected lifetime of materials exposed to space for long periods. Furthermore, the data made a valuable contri-



Assembly of Lageos satellite at MSFC

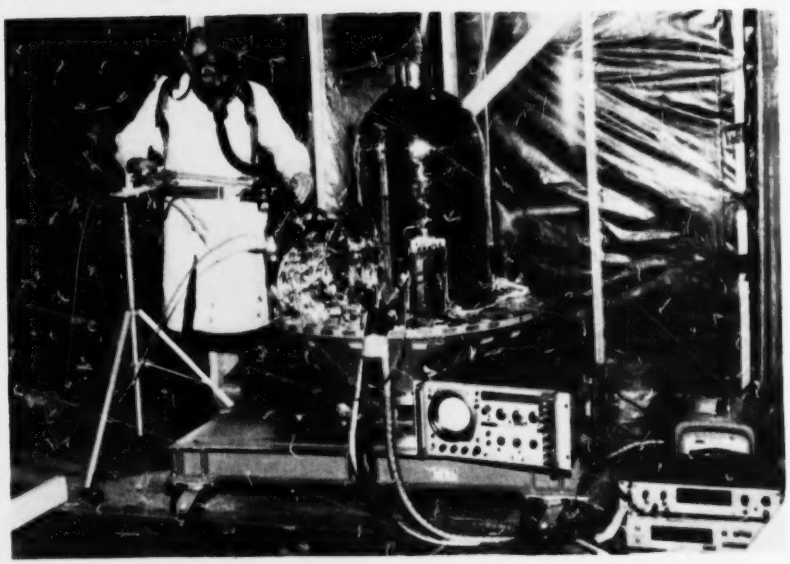
bution to general knowledge of the nearby space environment; facts replaced theory.

During the period after Pegasus, the focus of scientific activity at Marshall was on various experiments to fly aboard Skylab, the nation's first orbital laboratory and space station. As discussed elsewhere in this text, Marshall's multidisciplinary space science capabilities grew noticeably stronger during the Skylab era. Meanwhile, two satellites were being developed for quite different missions, one practical and the other theoretical. In 1976, Marshall launched both the Laser Geodynamics Satellite (Lageos) and the Gravitational Redshift Probe A (GP-A).

Lageos, which is still in orbit, is essentially a mirror in space. The 900-pound, 2-foot diameter satellite precisely reflects laser beams from ground stations for extremely accurate ranging measurements. The purpose of Lageos is to measure movements of Earth's crust; movements of less than an inch can be detected by timing the laser beam's 3700 mile round trip. The practical application of this ranging system is improved understanding of earthquakes, continental drift, and other geophysical phenomena. The satellite was conceived and manufactured at the Marshall Center.

The purpose of the 125-pound Gravitational Probe (GP-A) was more abstract: to test the principle of equivalence in Einstein's

"We must look beyond our limited horizons to discover the laws of science and the sources of energy that will govern our future on this planet."
Dr. Eberhard Rees, 1970



Final checkout of GP-A experiment at Marshall

general theory of relativity. According to theory but never demonstrated, a clock will appear to run faster in a weaker gravitational field, at a greater distance from Earth. Scientists from Marshall and the Smithsonian Astrophysical Observatory jointly devised an ingenious experiment to test the theory. A very stable atomic clock was launched through Earth's gravitational field to a peak altitude of 10,000 km (6200 mi.), and its readings during free flight were compared with those of an identical reference clock on the ground. The experiment lasted about an hour, and results confirmed the theory. Marshall had overall management responsibility for the construction, integration, and systems testing of the satellite. The Marshall-designed thermal control system met unusually stringent requirements.

Marshall scientists have developed a great variety of small payloads for rocket flights. Astronomers, solar scientists, magnetospheric and atmospheric physicists rely on these small experiments to gather data and test new instrument concepts. One of the Center's most successful efforts for small payloads has been the Space Processing Applications Rocket (SPAR) project. Between 1975 and 1983, Marshall accomplished 10 suborbital flights which altogether carried several dozen small materials processing experiments. Intriguing results were achieved in the five-minute periods of near weightlessness as the rocket passes through its apex. (Microgravity materials processing research is discussed in detail elsewhere in this text).

Small scientific payloads have an important place in Marshall's history on their own merits and as forerunners of more ambitious efforts. For example, Pegasus data are still consulted today as the standard reference on micrometeoroids. Rocket-borne payloads have served as economical test beds for new concepts, and they bridged the period between Skylab and Shuttle flight opportunities.

With the advent of the Space Transportation System, scientists are now concentrating on experiments to be flown on Shuttle and Spacelab missions. These new facilities are preferred because experiments can be flown frequently for a week at a time, operated by crew members, and returned for analysis, modification, and reflight. Many of the Center's scientists are thus developing small payloads for manned missions in space.

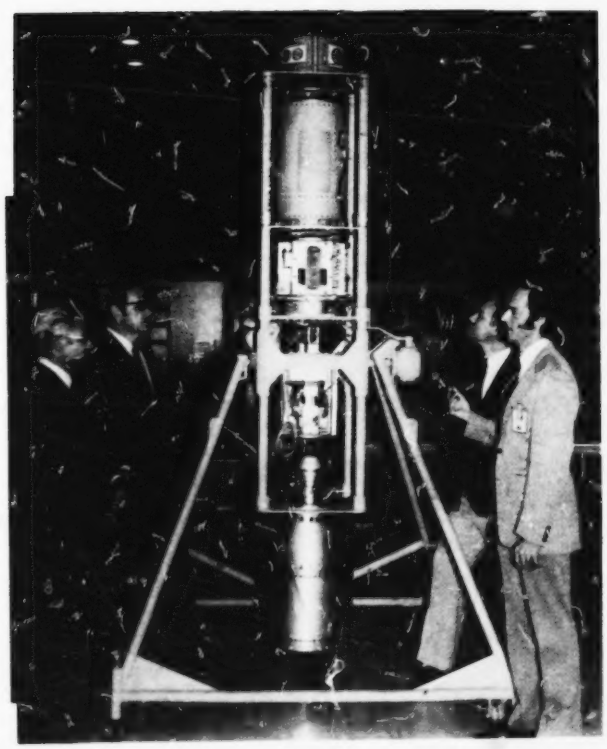
Space Observatories

Given its expertise in developing large launch vehicles, it is not really surprising that Marshall Space Flight Center has also developed large scientific systems. Over the years, the Center has been responsible for a family of observatory-class payloads, large complements of instruments designed to operate together and make related scientific observations. Just as an observatory on the ground contains various instruments for the common use of many scientists pursuing their own research, so the big systems developed at Marshall function as observatories.

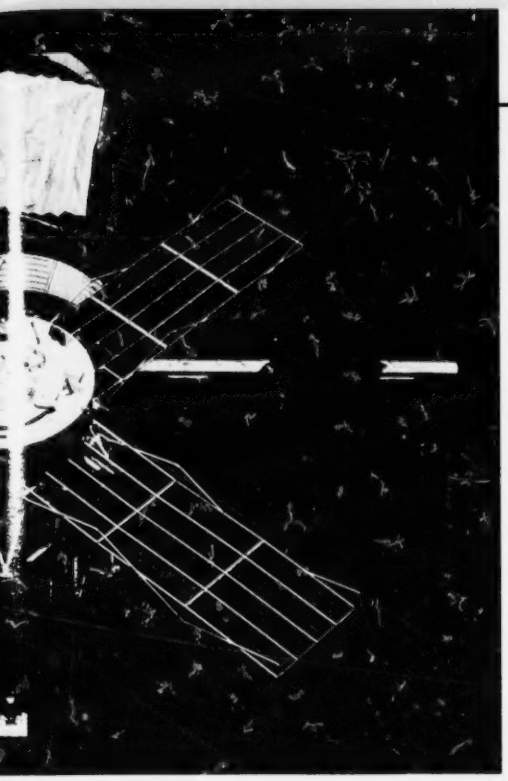
The lineage to date includes the Apollo Telescope Mount on Skylab (1973), the three High Energy Astronomy Observatories (1977-79), the Hubble Space Telescope (scheduled for launch in 1986), and the planned Advanced X-Ray Astrophysics Facility (1991). Each of these observatories is a unique scientific resource, offering scientists around the world the most advanced technology available in its time for new insight into the universe.

Circular Apollo Telescope Mount, a sophisticated solar observatory

Apollo Telescope Mount – first manned observatory in space.



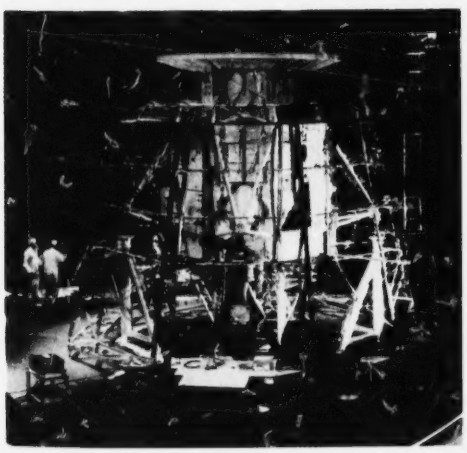
Materials processing experiments for a SPAR flight



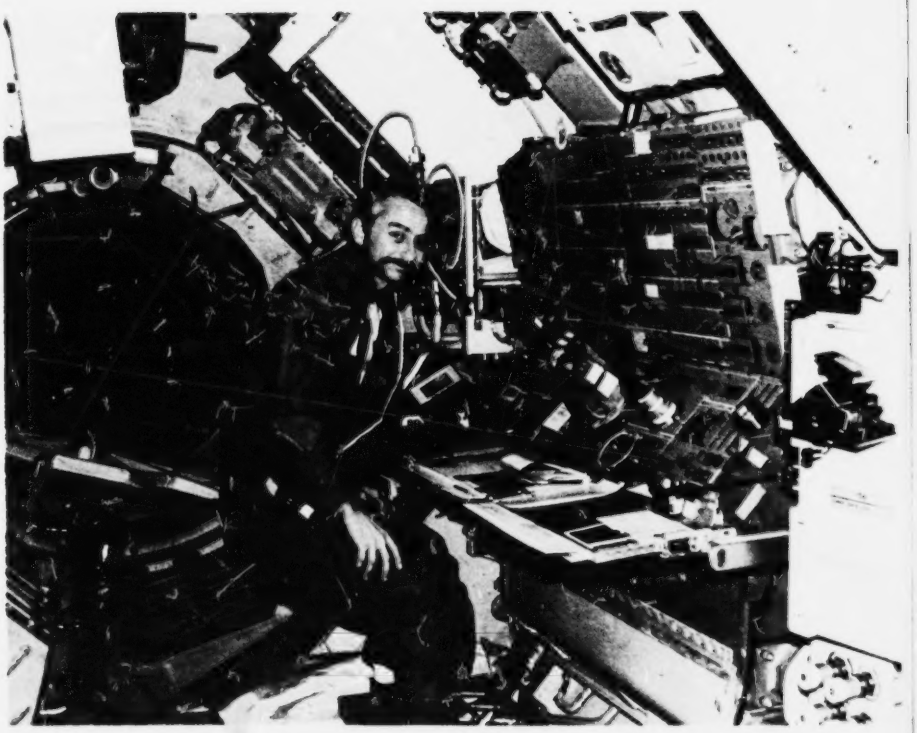
RESEARCH ON THE NEW FRONTIER

Skylab Apollo Telescope Mount

Marshall's first endeavor in observatory-class payloads was the Apollo Telescope Mount developed for use with the Skylab orbital workshop. A complement of six solar telescopes and two related cameras, the observatory compared favorably in size and pointing capability to some of the best observatories on the ground. Yet, the observatory in space revealed the sun as it could never be seen from the ground underneath the obscuring atmosphere. The Apollo Telescope Mount was an unprecedented tool for solar research, and the Marshall Center played a major role in its development and operation.



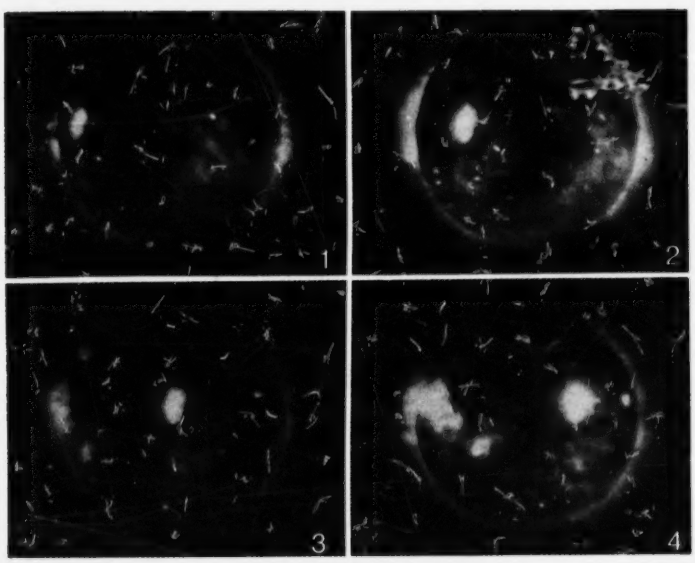
ATM thermal testing in MSFC vacuum chamber



Skylab scientist-astronaut at the ATM control console

RESEARCH ON THE NEW FRONTIER

New views of a familiar sun in visible light, X-rays, hydrogen-alpha, and ultraviolet light



Changing coronal hole visible in X-ray images

Although its mission occurred in 1973, the observatory concept originated in 1965, when NASA began to consider a program to succeed the Saturn-Apollo missions. Called the Apollo Applications Program, the effort was directed to the use of Saturn-era technology for new purposes. At the crux of the program were concepts for converting a spent Saturn stage into an orbital workshop or precursor space station. The Apollo Telescope Mount evolved from a fairly simple initial concept into an advanced observatory attached to such an orbital workshop.

In 1966, Marshall Space Flight Center was assigned responsibility for developing the solar observatory. While six of the eight instruments were developed at other research institutions, Marshall coordinated the design, integration, and assembly into a single payload. In addition, the Center developed two scientific instruments and designed, produced, and tested the mount for the entire cluster. Marshall also was responsible for the attached laboratory module, called the Multiple Docking Adapter, which housed the control and display console for the observatory and a complement of Earth resources experiments. The Apollo Telescope Mount project drew upon all the scientific, engineering, and managerial talents of the Center.

The purposes of the Apollo Telescope Mount were to observe, monitor, and record solar features over a wavelength range from visible light through ultraviolet and X-ray emissions. Each of the instruments was the most advanced of its type; used together, they could examine different layers of the solar atmosphere or simultaneously scrutinize the same solar feature across the spectrum.

Marshall engineers met a number of challenges to provide an observatory mount that would enable the instruments to take full advantage of being in space. Besides providing a large optical bench and a protective canister to support and enclose the instruments, Marshall was responsible for the power, thermal, pointing, and deployment systems. The control and display and data systems also were developed under the Center's auspices. Marshall had overall systems integration responsibility, including alignment and calibration for the entire observatory.

By 1968, Marshall had awarded contracts to various industrial partners. Bendix, for example, produced an attitude control gyro for extremely precise pointing accuracy and stability. Martin Marietta was assigned the payload integration function and assembly of the con-

trol console. The thermal systems unit and outer canister were assembled in-house in the Center's Manufacturing Engineering Laboratory. By mid-1970 the Apollo Telescope Mount design received final approval, and a year later the flight unit underwent engineering tests in Huntsville and Houston.

In the meantime, a full-scale mockup of the observatory was installed underwater in Marshall's Neutral Buoyancy Simulator in 1969. Because the primary data collection was photographic, the crew had to change film cartridges periodically, a task done outside Skylab. Thus, extravehicular activity (EVA) reviews and crew training exercises were conducted in a simulated zero-gravity environment at Marshall to evaluate the crew aids and procedures for changing film and otherwise servicing the observatory.

The nine-month operation of the Skylab solar observatory was a stunning success. A harvest of more than 150,000 photographic exposures was collected, and observations revealed many unsuspected solar features and events. In particular, the Skylab data gave scientists an appreciation for the importance and complexity of the sun's magnetic fields. With its precise pointing accuracy and stability and its array of sensitive detectors across a wide wavelength range, the observatory revealed the sun as it had never been seen before. Solar scientists at Marshall and elsewhere gained a wealth of new information that far exceeded their expectations.

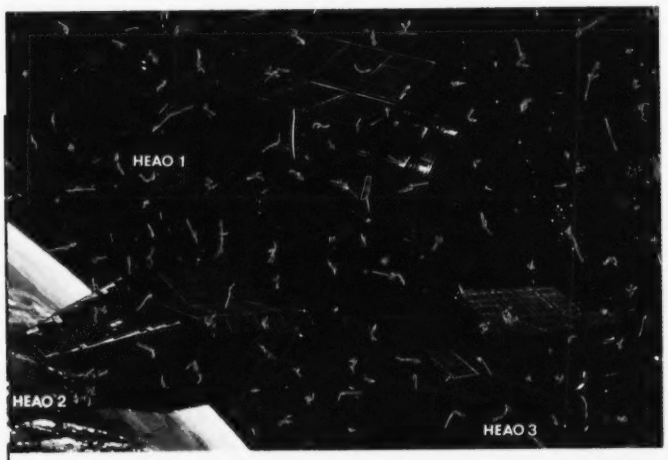
Credit for the success of the observatory belonged not only to the instrumentation, which had been developed and assembled under Marshall Center management, but also to the crew, who were well-trained in solar physics and operation of the telescopes. They knew what to look for and how to use the telescopes in concert to gain the most revealing information. They stayed on the alert for signs of interesting solar activity and responded to many opportunities beyond the scheduled observations. Furthermore, their ingenuity in troubleshooting and repairing instruments greatly enhanced the scientific yield of the mission. Marshall had participated in training the astronauts and justifiably felt pride in the crew's fine performance.

Marshall scientists and engineers also were involved in mission support during the nine-month period of Skylab orbital activity. Responsibilities included monitoring the Apollo Telescope Mount experiments and subsystems from the Huntsville Operations Support Center and monitoring the scientific observations from the operations control center in Houston. The Skylab solar observing program was carefully planned before the mission but was updated daily in response to observations and predictions from a worldwide solar watch. Investigative teams, including Marshall scientists, met daily to assess data and coordinate upcoming observations. During the mission, their communication with the crew was a contributing factor to the highly successful use of the observatory.

The Skylab Apollo Telescope Mount project was Marshall's first experience in developing and managing a major scientific payload for a manned mission. In this effort, the Center built new capabilities in scientific instrumentation, crew systems, and crew training. The Skylab experience became the foundation for increasingly ambitious ventures in observatory development and the use of space for scientific research.

Telescopes in space have opened our eyes to a new universe, invisible from the ground.

Solar flare viewed in ultraviolet light



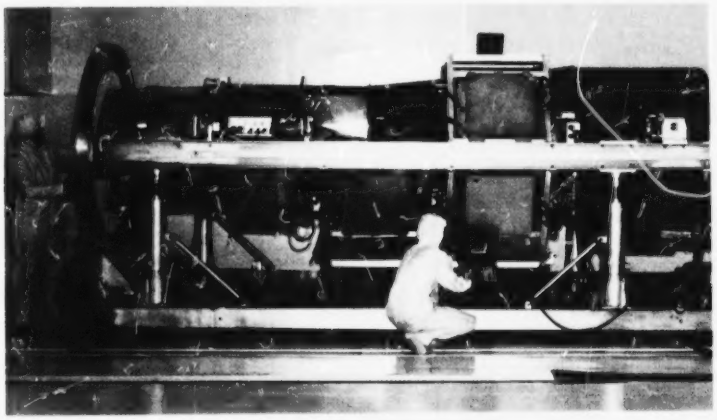
The family of High Energy Astronomy Observatories

High Energy Astronomy Observatories

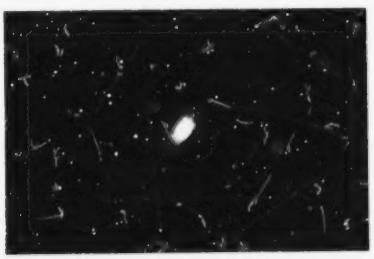
As the Apollo Telescope Mount project reached its culmination, a new observatory project was taking shape at Marshall – a series of three large, unmanned observatories for X-ray, gamma ray, and cosmic ray investigations. The Center served as project manager for the development of the High Energy Astronomy Observatories (HEAO), working with TRW, the prime contractor for the spacecraft. The scientific instruments aboard the observatories were designed by scientists at universities and other research centers, with technical inputs from Marshall.

The HEAO program spanned the decade of the seventies from early planning in 1970, through the year of peak activity in 1976, to the launches in 1977, 1978, and 1979. With these observatories, the new field of high energy astrophysics came of age. Thousands of celestial X-ray and gamma ray sources were discovered as astronomers had their first long, clear look at the universe in this fairly unfamiliar part of the spectrum. For the first time, they had sharply focused X-ray images of distant galaxies, supernova remnants, pulsars, quasars, and other intriguing objects. The quick pace of discovery, revealing highly energetic objects and events, changed astronomers' understanding of the universe almost overnight.

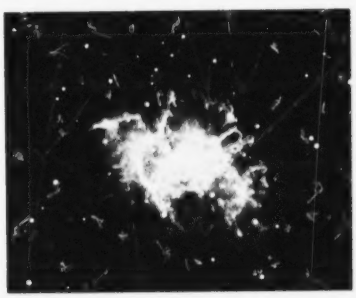
As usual, the Center's laboratories were heavily engaged in the technical and scientific



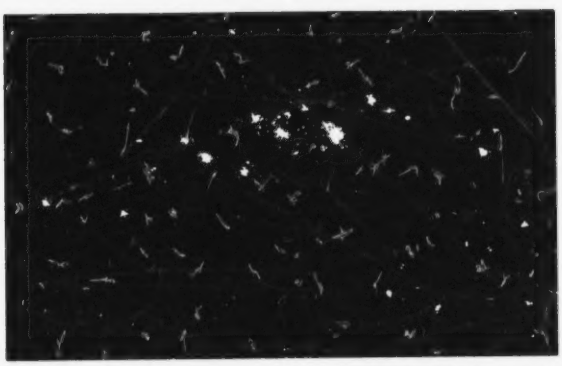
Checkout of HEAO-2 telescope at MSFC



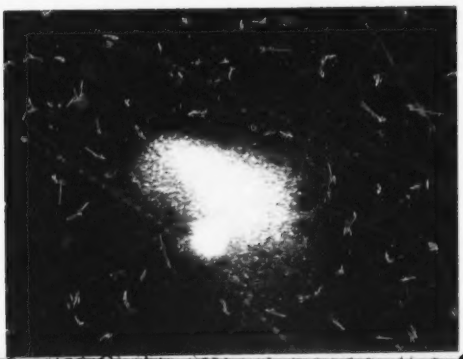
Andromeda Galaxy in visible light



Crab Nebula in visible light



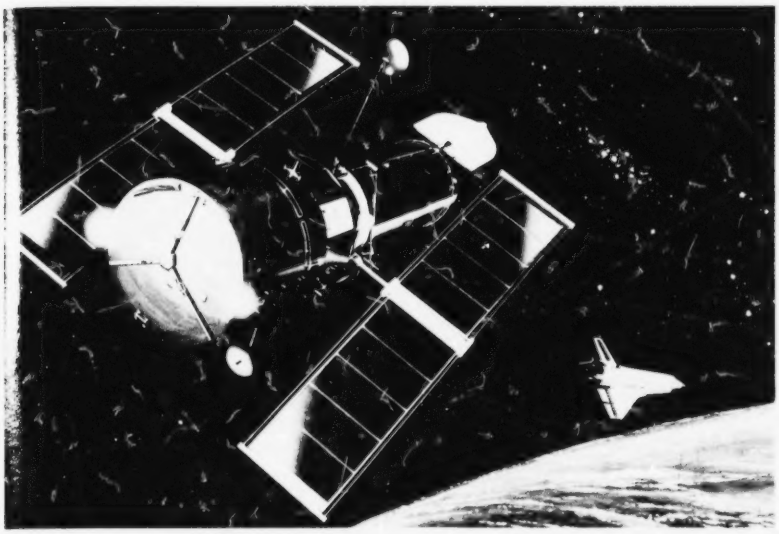
HEAO image showing X-ray sources within Andromeda



Hidden pulsar in Crab Nebula, revealed in HEAO X-ray image

Hubble Space Telescope

Currently, the Marshall Center is managing one of the most exciting scientific payloads in its history – the Hubble Space Telescope, named in honor of the twentieth-century American astronomer Edwin P. Hubble. Heralded as perhaps the most important scientific instrument ever flown, the Space Telescope is expected to revolutionize modern astronomy and to serve as the world's premier astronomical research facility for the rest of the century. It is an imposing instrument; 43 feet long, 14 feet in diameter, with a 2.4-meter (94-inch) primary mirror and five large detectors, the telescope weighs 12 tons. The Space Telescope will enable astronomers to see 7 times farther into space and observe objects that appear 50 times fainter than they can see from the best ground-based observatories.



Hubble Space Telescope, premier space observatory for the next generation

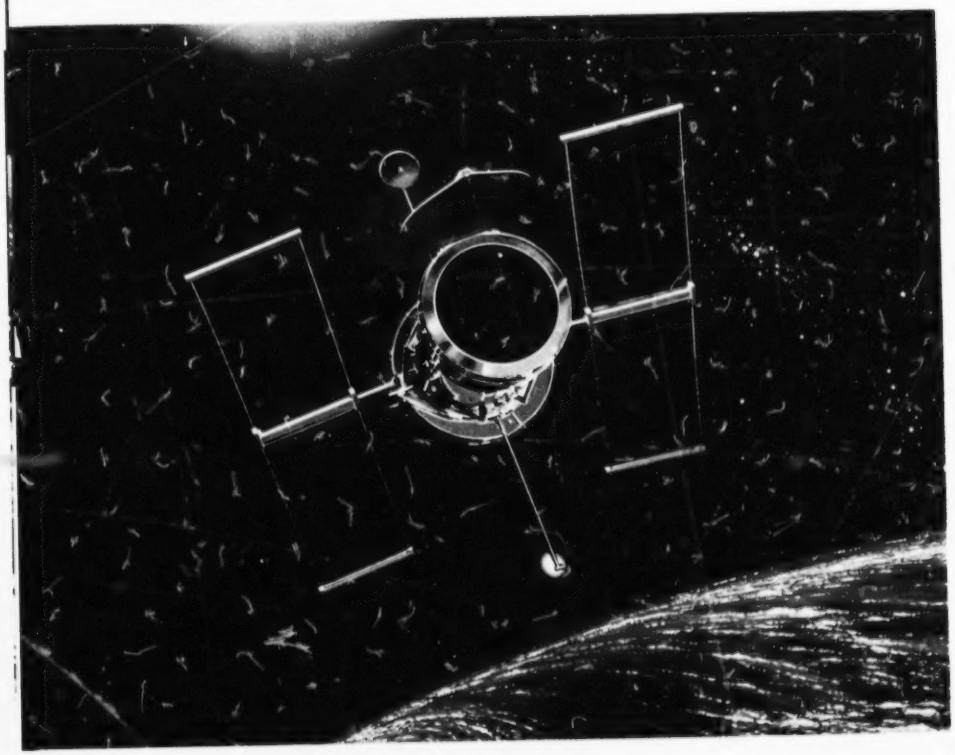
aspects of the new observatories. A highlight of Marshall's involvement was the testing and calibration of the HEAO-2 telescope, the first imaging X-ray telescope and the largest X-ray telescope ever built. To qualify this remarkably precise instrument and others in the future, Marshall erected a unique X-ray calibration and test facility, larger and more sophisticated than any in the world. Completed in 1976, the facility contained a 1000 foot long by 3 foot diameter vacuum tube (for the X-ray path) connecting an X-ray generator and an instrument test chamber.

The HEAO missions were unqualified successes. All spacecraft exceeded their expected lifetimes and the resultant data collection was enormous. In their day they were the largest automated scientific payloads with the lowest cost per pound ever placed in orbit. In the course of the program, there were technical difficulties with the advanced gyro and mirror technology needed to meet the rigorous pointing and sensitivity requirements. In addition, the Center encountered new management challenges, for the HEAO program fell within NASA's period of retrenchment. With constrained budgets and reductions in work force, the HEAO program was descoped more than once. Marshall and its partners had to rethink and restructure the missions within new constraints. Nevertheless, the observatories were immensely successful, and Marshall's reputation for developing and managing scientific payloads grew.

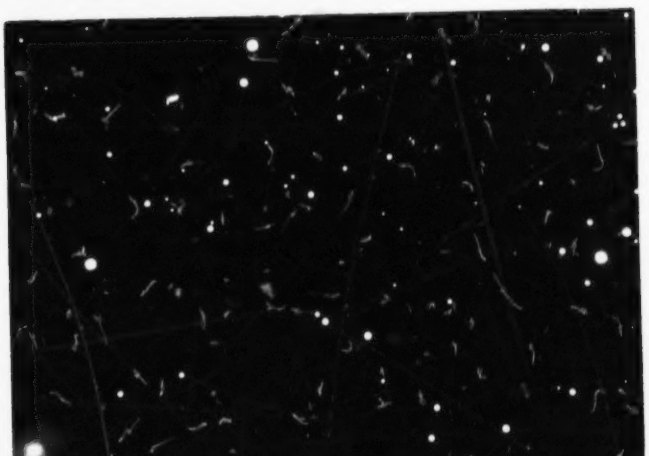
Inspecting the huge primary mirror before installation in the telescope

Neutral buoyancy mockup for crew training

RESEARCH ON THE NEW FRONTIER



Exploring the universe with powerful new telescopes



Following various science and engineering concept studies in the late 1960's, Marshall Space Flight Center was assigned Space Telescope project management responsibilities in 1972. For the next five years, the Center conducted various studies both in-house and under contract to define the science and engineering requirements. By 1977, the basic observatory design was settled and contractors were selected for two of the major elements – Perkin-Elmer for the Optical Telescope Assembly and Lockheed Missiles and Space Company for the Support Systems Module and systems integration. NASA's Goddard Space Flight Center was assigned responsibility for development of the scientific instruments. In exchange for a percentage of viewing time, the European Space Agency agreed to provide the solar array power system and one of the scientific instruments. The Center already has done much of the definition and systems engineering work in-house; Marshall is now busy managing the hardware deliveries and assembly in preparation for launch.

The Space Telescope represents a new observatory concept, one designed to be launched by the Space Shuttle and serviced in space by astronauts. This new feature introduced new challenges for the project management team.

More than any other previous scientific payload, the Space Telescope has tasked Marshall's crew systems experts to develop the tools, workstations, and procedures for orbital servicing. For several years in laboratory and neutral buoyancy tests, they have evaluated extravehicular activity techniques for normal and contingency servicing tasks, such as replacing components, removing scientific instruments, and handling solar arrays.

The Space Telescope project also has tapped the Center's resources for structural, electronics, and thermal control engineering. Support teams in the laboratories have worked on alignment, thermal balance, contamination control, and pointing. In-house design, test, and analysis were especially important in development of the instrument latches and the telescope's fine guidance sensors.

Both major elements developed under Marshall's management – the Optical Telescope Assembly and the Support Systems Module – presented challenging technical problems. There was no precedent in space hardware for the primary mirror, which had to be large and lightweight with an ultra-precise reflecting surface. Similarly, there was no com-

parable pointing and attitude control system; to detect and make images of very faint objects, long duration exposures are necessary, which means that the telescope must maintain accurate, stable pointing for hours. Both the mirror and the pointing and control system were quantum leaps in the capability of space astronomy hardware.

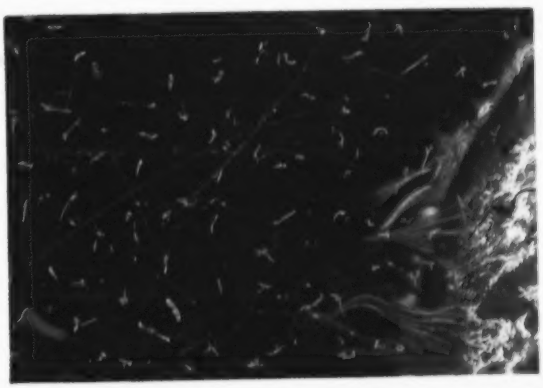
The Marshall Center plays a major role in ground tests and orbital checkout of Space Telescope. Marshall personnel are preparing test plans and monitoring test activities before launch to verify that the telescope responds to commands and puts out data properly. Tests on the launch pad will be monitored from the Huntsville Operations Support Center (HOSC). The Marshall HOSC team will actively support tests of the telescope and science instruments during Space Telescope's first six months in orbit. The Hubble Space Telescope is the nation's biggest single investment in space science. Its development costs and progress have attracted considerable public attention, and the telescope's fortunes and schedules have been linked to the Shuttle's. Marshall has kept the project on course despite a troublesome share of technical and budgetary difficulties. Space Telescope is scheduled for a Shuttle delivery in 1986. As launch of the observatory nears, astronomers around the world eagerly await an extraordinary view of the universe.

"There is good reason to believe that the Space Telescope . . . will be the most important scientific instrument ever flown."
James M. Beggs
NASA Administrator, 1982

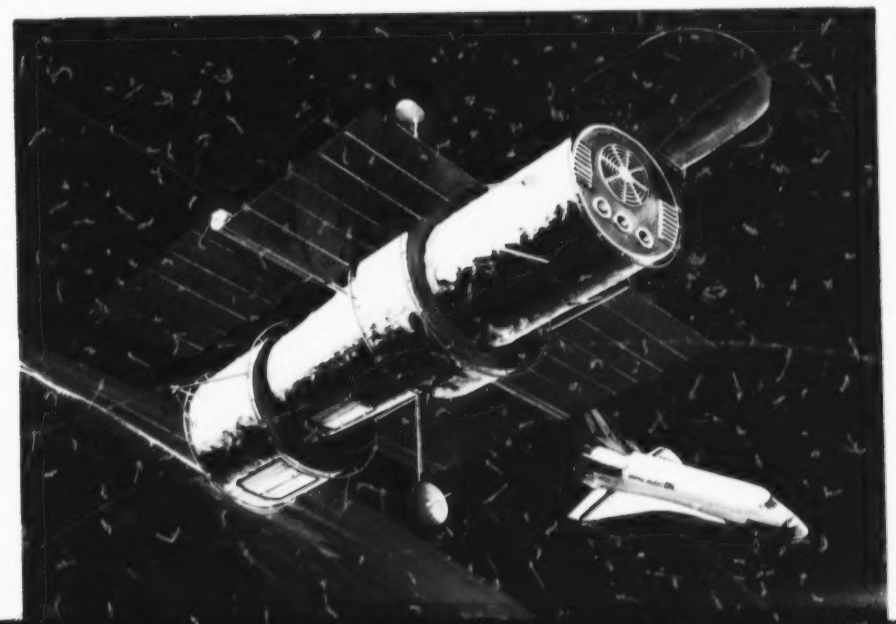
Advanced X-Ray Astrophysics Facility

The newest member of Marshall's family of space observatories is the planned Advanced X-Ray Astrophysics Facility (AXAF), which builds on experience gained in both the High Energy Astronomy Observatories and the Hubble Space Telescope projects. Like the former, it is an observatory for X-ray investigations but with appreciably improved capabilities; like the latter, it is designed to be launched from the Shuttle and serviced in orbit. In the nation's strategy for astronomical research, the AXAF is intended to be a companion to the Space Telescope and other advanced observatories for a coordinated, broad spectrum study of the universe.

In 1978, Marshall and the Smithsonian Astrophysical Observatory completed a joint conceptual design study for this new telescope. Since then, both partners have worked with an astrophysics advisory group to define scientific requirements and a desirable set of focal plane instruments. Project definition activity is now in progress.



Seeking to understand black holes and other enigmas



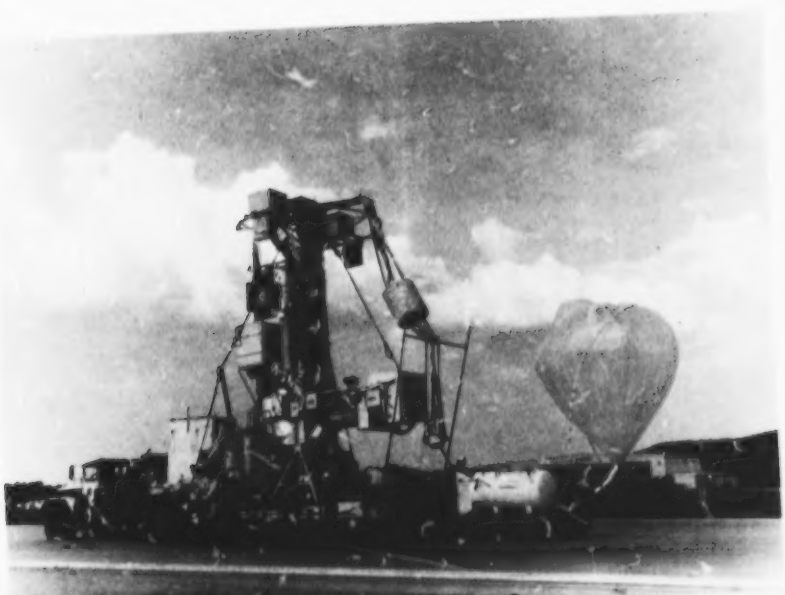
AXAF, planned X-ray observatory

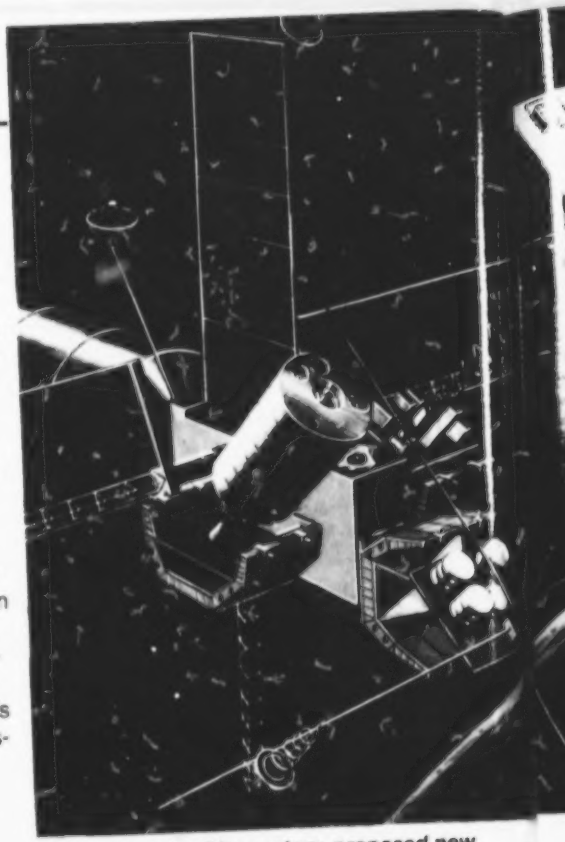
RESEARCH ON THE NEW FRONTIER

In size and shape, the proposed X-ray observatory bears a family resemblance to Space Telescope. Inside, however, the two are entirely different: the X-ray mirror is a set of nested cylinders. The AXAF telescope is an enlarged, improved model of the HEAO-2 grazing incidence mirror system, with much greater accuracy. Marshall laboratories (jointly with Perkin-Elmer and Itek) are engaged in a Technology Mirror Assembly program to test the AXAF high-resolution mirror concept using the X-ray calibration facility.

Although the AXAF has not yet received funding for development, it has been designated the highest priority astrophysics observatory by the National Academy of Sciences. An X-ray telescope gives access to violent, high-energy phenomena associated with the evolution of the universe. The Advanced X-Ray Astrophysics Facility is the next step in NASA's trend toward long-lived observatories for investigations across the spectrum.

Space science leads us from mystery to discovery and understanding of the universe.





Advanced Solar Observatory, proposed new eye on the sun

New Solar Observatories

Two new solar observatories are being planned at the Center for eventual installation on the Space Station. Flight experiments in solar observation and imaging may be expanded and combined to form a Pinhole Occulter Facility and an Advanced Solar Observatory. Both observatories offer long-term, highly accurate operations of complementary instruments for a coordinated study of the sun across the electromagnetic spectrum. A Solar-Terrestrial Observatory also is being planned to help understand the complex interactions between the sun and Earth, particularly their effects on long-term trends in weather and climate. These proposed new observatories represent an evolution of both Skylab and Shuttle/Spacelab science. In the future, they may serve solar science as Space Telescope and AXAF serve astronomy and astrophysics

Spacelab Investigations and Other Experiments

Over the years, Marshall Center scientists and engineers have spawned a multitude of science and technology experiments for flights on aircraft, balloons, rockets, or spacecraft. At any one time, about 50 such projects are under way at the Center, and a chronology of these

Cloud physics research aboard NASA's KC-135 microgravity research aircraft

Preparation of the Spacelab 2 Infrared Telescope

achievements would easily fill another volume. Rather than a comprehensive history of all flight experiments, a summary of recent highlights suggests the variety of research programs and flight opportunities that attract and occupy many of Marshall's experts in the science disciplines.

These flight experiments arise from many laboratory disciplines within the Center, with the heaviest concentration in the Space Science Laboratory. As more and more experiments are developed for flight aboard the Shuttle and Spacelab, Marshall's own scientists are "customers" for the Center's mission management service. Marshall people also serve as co-investigators for many experiments on spacecraft developed or managed elsewhere.

In astrophysics, scientists here are still immersed in HEAO data analysis and in science planning for the AXAF. Additionally, the Center has mission management responsibilities for three Shuttle flights of the Astro ultraviolet observatory and is developing a special wide field camera as part of that payload. Marshall also provided flight hardware and test services for the Spacelab 2 Infrared Telescope (1985). Planning is under way for two new facilities – a Very Long Baseline Array (VLBA) and

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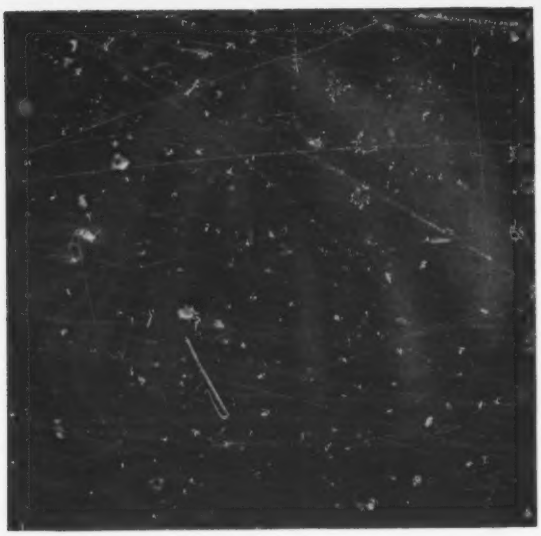
Preparing the Geophysical Fluid Flow Cell (GFFC) experiment for Spacelab 3 flight

a Coherent System of Modular Imaging Collectors (COSMIC). The Center also supports ongoing balloon flights of gamma ray and cosmic ray detectors. One such small payload has evolved into a major instrument on the Gamma Ray Observatory; Marshall is designing, building, and testing the Burst and Transient Source Experiment (BATSE) in-house. Eight BATSE modules for the spacecraft are being produced by the Marshall principal investigator and engineering team.

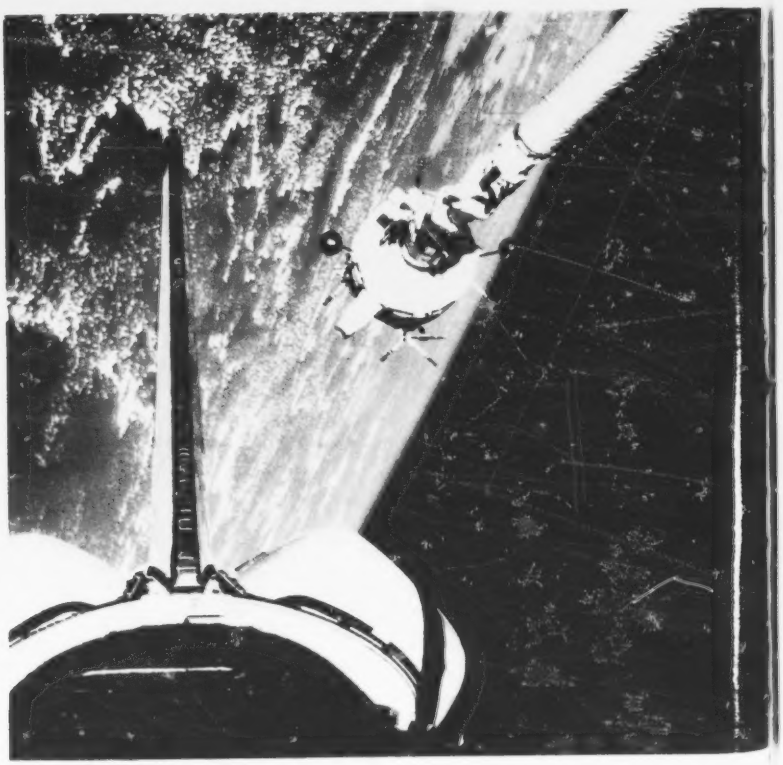
The general thrust of atmospheric science flight experiments has been to understand natural processes, such as circulation and lightning, in Earth's atmosphere. Data from sensors at high altitudes are needed to refine conceptual models of the behavior of Earth's environment. Ultimately, experiments may lead to improved prediction and other practical applications. Two experiments with Marshall co-investigators recently flew on the Shuttle, a Geophysical Fluid Flow Cell on Spacelab 3 (1985) and an Optical Survey of Lightning on several earlier Shuttle missions.

For a number of years, Marshall scientists have been investigating the sun and its influence on Earth's magnetosphere and ionosphere. Solar-terrestrial physicists are using space as a vast natural laboratory for observations and active experiments that stimulate the environment to provoke responses similar to natural processes. Recent highlights include stunning data from Marshall instruments on Dynamics Explorer (1981) and other spacecraft and from missions with Marshall investigators, such as the Solar Maximum Mission (1980) and Spacelab 1 (1983). The Center has been involved in several Shuttle-borne space plasma experiments that have flown and will fly again; these include an electron beam accelerator (SEPAC), a plasma diagnostics satellite (PDP), and an atmospheric imaging instrument (AEPI). A variety of sounding rocket investigations also have been completed. Besides developing instruments for many of these projects, the Center's scientists are heavily involved in data analysis and publication of results. Major scientific contributions include new insights into solar flares and magnetic fields and new evidence of the ionosphere as a major plasma source for the magnetosphere.

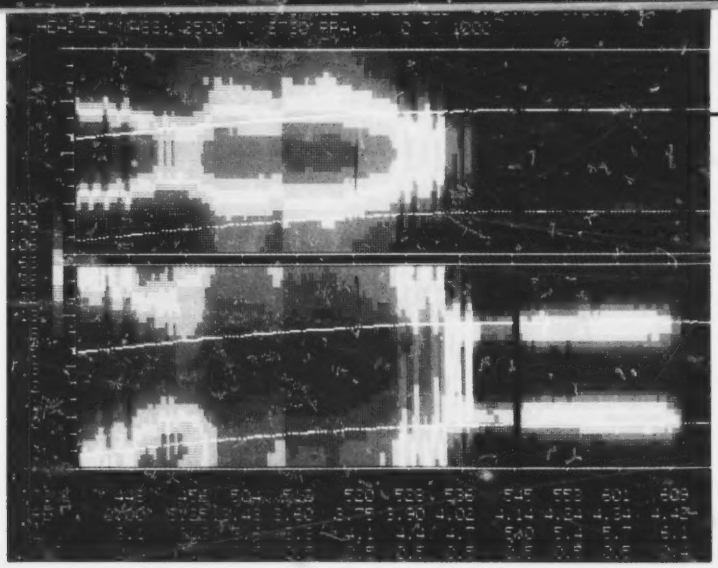
A new project now under development is a tethered satellite to be towed by the Shuttle through otherwise inaccessible regions of the upper atmosphere. Marshall has project management responsibility for this international endeavor with the Italian space agency and



"Banana cell" pattern of fluid motion observed in GFFC experiment in space



Monitoring Earth's space plasma environment from the Space Shuttle



Features of Earth's nearby space environment revealed in data from MSFC instrument on Dynamics Explorer satellite

also has principal investigators for two scientific instruments. The Center will develop the tether, a thin cable that can be reeled out to a length of 60 miles. In addition to planning the science program for tethered experiments, Marshall is responsible for a broader tether applications in space program. This effort involves studies of tethered science platforms and tethered transportation related to the Space Station.

Technology flight experiments generally are demonstrating new structural concepts. For example, a very large, lightweight solar array developed at Marshall was structurally and dynamically evaluated during a 1984 Shuttle mission (OAST-1). The Solar Array Flight Experiment demonstrated advanced technology for using the sun's energy in space and for remote sensing and dynamic analysis of large space structures. Planned technology experiments include demonstrations of large-scale structural assembly and deployable antennas. Although the majority of the Center's technology research occurs in laboratories on the ground, a growing number of Marshall scientists and engineers are investigators for flight experiments.

"History tells us that it pays in unexpected ways to attempt to satisfy our curiosity about the universe."
Dr. Eberhard Rees, 1970

Tethered satellite for exploring hard-to-reach regions of the upper atmosphere

Advanced technology solar array tested in space

Materials Processing in Space

Using sound waves to suspend a drop in mid-air

Removal of solidified metal sample after free-fall in MSFC's 100-foot drop tube

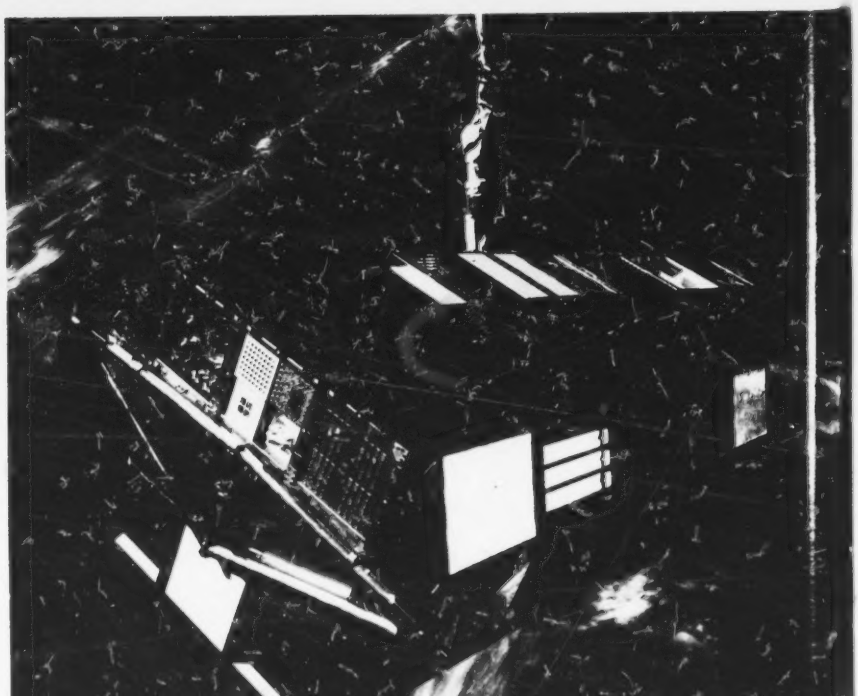
Materials processing – basic research and commercial development of new products.

Marshall Space Flight Center has a long tradition of microgravity research in materials processing. Exploratory investigations began during the Apollo era and were expanded in the Skylab research agenda. Early results confirmed that certain processes could be performed in space and that the resultant materials were often superior to those produced on the ground. Materials processing in space looked promising as a technique for basic research and as a project for commercial development. Today, materials processing is one of the major activities proposed for the Space Station and could well represent a significant expansion in the commercial use of space. This would be a major new phase in the nation's space program. The Marshall Center has been assigned a leading role in the Materials Processing in Space program.

From modest beginnings, Marshall scientists learned valuable lessons in equipment design and processing techniques. Since no one knew just how the processing of materials would be affected by the low gravity of orbit, there was a great deal of trial and error and modifying early experiments for reflight. Marshall was involved in the development of microgravity furnaces, levitation devices for containerless processing, and electrophoretic (fluid separation) devices for biological processing from the outset, with first flight of such devices on the Apollo 14 mission.

Marshall also plunged into the effort to build up a data base of ground-based research

ABOVE: Perfecting techniques for casting alloys of materials that do not mix naturally



RIGHT: Hundreds of material samples, some provided by Marshall, exposed to the space environment

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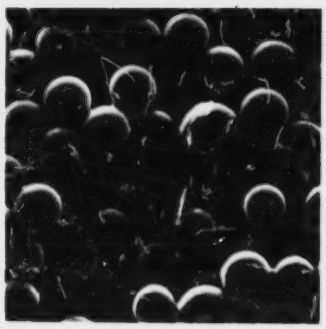
to guide and compare with space experiments. During the 1970's many experiments were conducted in the Center's laboratories, a drop tower and tube on a rocket test stand, and NASA's KC-135 aircraft. In the few seconds of near weightlessness that could be achieved, scientists gained valuable insights into the processes of crystal growth, solidification, and containerless confinement of materials. For eight years, Marshall managed a series of Space Processing Applications Rocket (SPAR) flights that provided about five minutes of microgravity for materials processing experiments.

Now the Shuttle and Spacelab are being used to study the effects of gravity on materials processing. Marshall has recently developed, managed, and flown a reusable Materials Experiment Assembly for investigations in the growth of high-performance crystals for semiconductors, the formation of unique alloys and glasses, and the preparation of very pure materials by containerless processing and ultra-high vacuum processing techniques. In a joint endeavor arrangement pioneered and managed by the Marshall Center, NASA and private enterprise are working as partners to do research in fluid separation. Orbital tests of the Shuttle-borne Continuous Flow Electrophoresis System developed by McDonnell Douglas for the separation of biological materials such as blood cells and enzymes, indicate that processing in space is more efficient than processing on the ground. Another research project already has demonstrated commercial value; the Monodisperse Latex Reactor, developed by scientists from Lehigh University and the Center, has been successfully operated on the Shuttle. Its products, extremely uniform latex spheres, are now available for the commercial market as laboratory calibration standards. Besides developing experiments, Marshall scientists perform extensive postflight laboratory evaluations of the various materials processed in space.

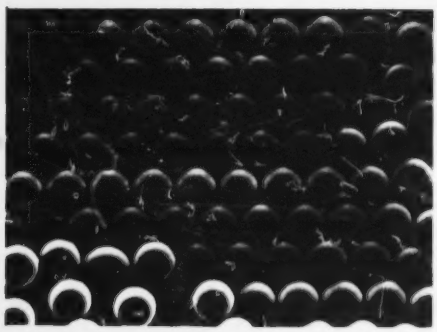
The microgravity research that began on Apollo, Skylab, and rocket flights, has evolved into a Marshall Center specialty with great potential not only for improved knowledge but also for commercial development in space. NASA has formally established a Materials Processing in Space program to encourage the academic and industrial research communities to make use of the space environment. The near-term goals are establishment of national and international microgravity science laboratories in space. Marshall is already involved in cooperative projects with industrial partners for microgravity flight experiments and facilities.

The longer-term goal is a permanent facility for commercial uses of space to solve important scientific and technical problems. In the microgravity environment, scientists can study basic properties of materials to better understand and control processes on Earth. These microgravity services are comparable to biomedical laboratory services on the ground. Space may prove to be an economically favorable production site; the market success of the first materials manufactured in space, the monodisperse spheres, is now being tested.

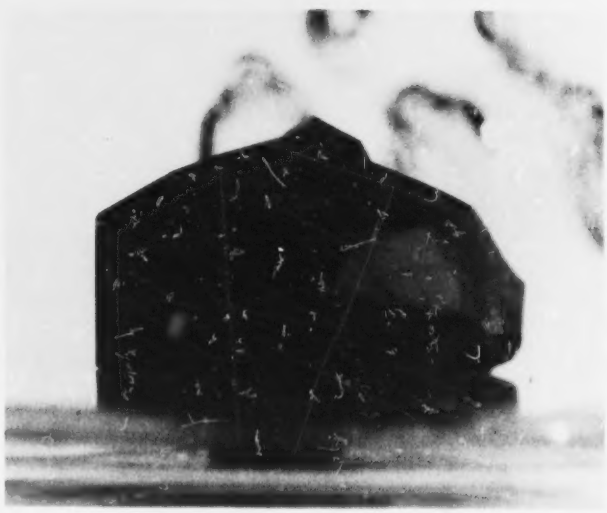
A vigorous Materials Processing in Space program is being pursued. The Marshall Center is playing an important role as NASA and the world prepare for the commercial uses of space.



Irregular latex spheres produced on the ground



Uniform latex spheres produced in space



A large and nearly flawless mercury-iodide crystal produced in space for potential uses on Earth

Research and Technology

Pushing technology beyond present limits

Studying the sun from the Marshall Center's observatory

A very important portion of the Marshall Center's work unfortunately attracts little public notice because it does not directly culminate in launches and flights. This is the work of scientists and engineers engaged in research and technology in the Center's diverse laboratories. These people address fundamental problems to advance the state of the art and the state of knowledge in their disciplines. Some of the most interesting history of the Center lies in their unrelenting efforts to understand nature.

Although this aspect of Marshall's activity is less visible to the public than hardware products, within the scientific and technical community the Center's cells of excellence are well known. Marshall's achievements in research and technology have been recognized as substantial contributions to knowledge and to progress within the space program. Furthermore, industry has made practical applications of many of these advances. Although the Center's accomplishments in research and technology merit a comprehensive historical survey, a review of some recent efforts may suggest the vigor and variety of Marshall's assault on the unknown.

In atmospheric science, researchers are involved in theoretical modeling to understand the environment. They attempt to extract from physical laws and observational data the explanations for natural processes, such as atmospheric turbulence, wind shear, circulation patterns, cloud formation, and severe storms. This work is relevant to understanding Earth's environment and other planetary atmospheres as well.

In astrophysics, researchers analyze and interpret data to understand celestial phenomena. Their work involves theoretical modeling as they try to answer basic questions about the universe: for example, what are black holes? By what process do quasars become the most powerful known sources of energy? Astrophysics research also involves the perfection of detectors to extend the range of observation to greater distances and sensitivities. Significant laboratory effort is devoted to the search for improved telescope materials and observational techniques.

Solar and magnetospheric physicists develop models of the sun, magnetosphere, and upper atmosphere to understand better the composition, density, temperature, and other features of these complex environments Enigmatic solar flares are being investigated with data from the Center's vector magnetograph facility, the only one of its kind in the

RESEARCH ON THE NEW FRONTIER

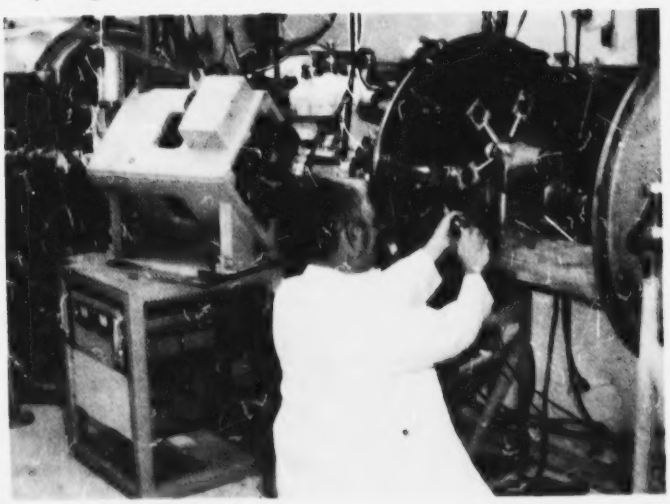
Inventive research in Marshall's laboratories

"As we identify needs that can be met through the use of space, or space technology, we will move to meet them."
Dr. W. R. Lucas

Analyzing data in quest of discovery

Scrutinizing materials to prevent failures

Subjecting materials to the rigors of space



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world, along with corollary data from other ground observatories and spacecraft. Interest in spacecraft charging and electrodynamic interactions between space plasma and other moving bodies has stimulated laboratory analyses. Furthermore, Marshall has developed a much-needed computer-linked data network to facilitate the sharing of space science information by scientists around the country.

Basic technology studies at the Center span virtually all the disciplines of engineering and materials science. Past breakthroughs in cryogenics, electronics, materials, and other technologies are mentioned throughout this text. Technology advances have always been the enabling agents that turn goals and requirements into reality.

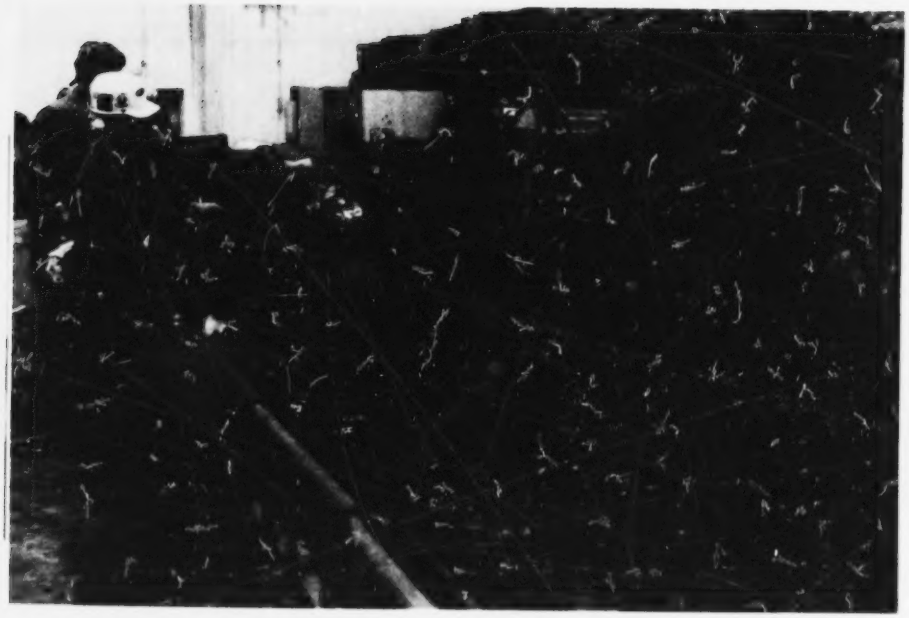
"Man's destiny lies in the exploration of space. It is the leading edge of our technology and from it already there have been many down-to-earth benefits in addition to the long range potential that awaits us in those distant places."

Dr. Wernher von Braun, 1967

Many current laboratory projects are directly related to the ongoing effort to improve the already reliable Space Shuttle, while others are longer-term studies to enable technology for future spacecraft. Diverse studies in propulsion technology, for example, include investigations of ignition and combustion processes, turbopump bearings and seals, nozzle materials, cryogenics, characteristics of propellants and materials, and powder metallurgy techniques. As a result, the design and operation of some Space Shuttle Main Engine components have been optimized, and uprated engines are now in service. Novel solar arrays and power system components are being studied for possible use on the Space Station. The Center has made strides in welding technology and robots that are of significant benefit to industry. Marshall scientists are engaged in many investigations of polymers, composites, ablatives, ceramics and coatings, lubricants and thin films. For many of these investigations, Center personnel also develop novel test equipment and test facilities, mathematical models, computer codes, and data bases.

As the Center moves into the Space Station era, it is investigating large space structures technology and operations. This multi-disciplinary effort involves evaluation of structural elements and materials, thermal control, dynamics, robotics and teleoperation, and crew systems for large platforms and antennas to be erected in space. The large space structures technology development program is intended to ensure that resources are available to meet future mission needs.

The Marshall Center has maintained a special technology utilization program to share the benefits of space technology with industry and public services. To date, several technology transfers in materials, electronics, pumps and valves have resulted in new products in the marketplace. Unusual spinoffs from Marshall technology include biomedical devices, energy conservation techniques, and fire fighting equipment. For several years, the Center played a leading role in national solar heating and cooling programs to develop and demonstrate solar energy systems and to stimulate their use. Marshall also investigated the adaptation of space technology for mineral extraction techniques in coal mining. Marshall actively pursues a variety of technology utilization projects that apply space technology to meet new commercial needs.



Down-to-Earth application of space technology for mining industry

ABOVE: Spacesuit technology to benefit firefighters
LEFT: Practical spin-off from NASA's pump technology

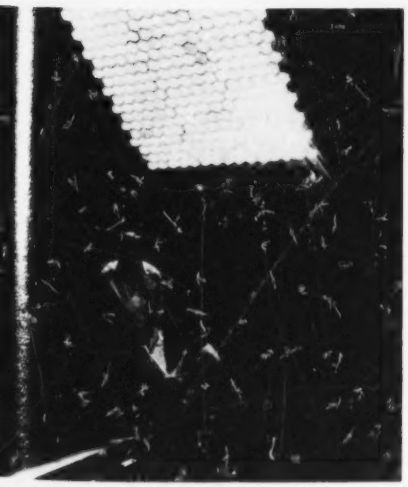
Legacies in Space Science and Technology

The litany of benefits from space science and technology is familiar: miniaturized electronics, solid state circuitry, insulation materials such as spray-foam and mylar foil, new plastics, new welding techniques, worldwide communication networks, freeze-dried foods, and many other products that have been marketed with success. These spin-offs have markedly changed the way people live, but they are by no means the only legacies. The intellectual benefit of space research is the primary legacy; people now know much more about materials, processes, Earth, and the stars. The space program has opened them all to scrutiny.

Two themes run through the Marshall Center's history in space science and technology: using space for research and developing improved means of doing that research. From rather modest early experiments to sophisticated observatories and instruments on the Space Shuttle, Marshall has earned impressive credentials.

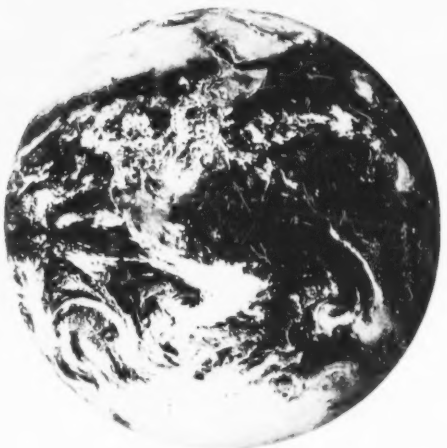
Among the most exciting scientific achievements of this Center was the Skylab Apollo Telescope Mount, which completely altered our understanding of the sun. Previously thought to be rather steady and calm except for periodic bursts of sunspot activity, the sun was revealed to be violently changeable over the course of hours or minutes. Scientists saw intriguing new phenomena, such as coronal holes, and witnessed scores of explosive flares. The program was a technical, scientific, and managerial success that demonstrated the value of a concerted assault on a particular scientific problem. The nine-month collection of Skylab solar data provided grist for analysis for almost a decade until a new solar observatory was placed in orbit.

Working with students to develop experiments for spaceflight



Learning how to harness solar energy

The complex environment of our planet



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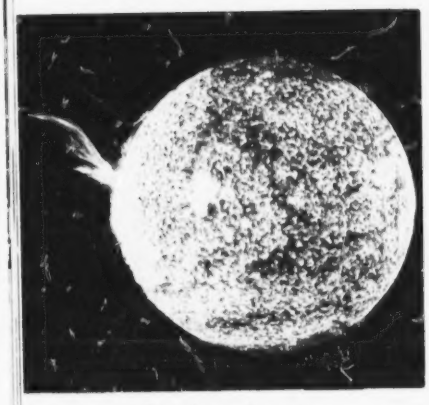


The dynamic sun

Similarly, the three HEAO missions provided a radically new view of the high-energy universe, punctuated by exploding stars and galaxies and permeated with radiation of mysterious origin. The HEAO surveys increased the catalogs of known high-energy sources many-fold and, like Skylab, provided enough data for years of analysis. The successor observatory, if approved for flight, is still several years from launch.

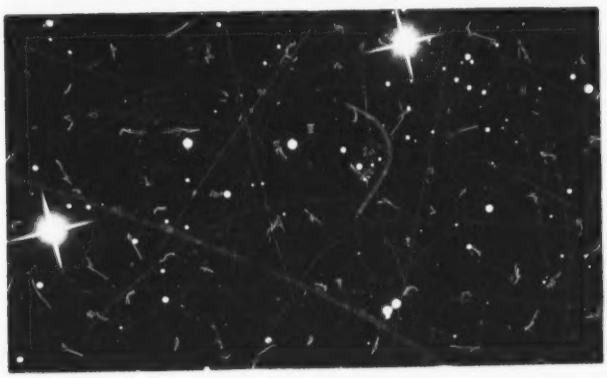
Another Marshall Center legacy is materials processing in space. Research here has demonstrated the advantages of microgravity for certain processes in crystal growth and alloy formation. Largely as a result of this work, space processing of materials appears to be a very promising, and commercially viable, new field. Microgravity research on or near the Space Station will focus on understanding and improving industrial processes on Earth, as well as processing products in space for use on the ground.

The Center's technology efforts enable the successful science and engineering programs. When programs require special thermal coatings or cryogenic fuels or ample power supplies or large but lightweight structures or high data rate telemetry or defect-free welds or zero heat leakage, the laboratories meet the challenge. Much of this technology passes on to industry for other applications.

A special benefit of the Center's technology efforts is the recent progress in productivity enhancement. As part of an economic drive throughout the agency and the federal government, Marshall has established a Productivity Enhancement Center to identify cost-saving improvements in programs. To date, significant savings have been realized by implementing such improvements.

In many of these research efforts, Marshall has developed partnerships with universities and private industry. These partners have contributed significantly to the Center's advances in science and technology. For the larger science projects, the Center has used task teams to organize early planning and development activities. The resultant contracting and management techniques have brought to fruition a great variety of research projects.

The science and engineering laboratories have always been one of Marshall Space Flight Center's greatest assets. During the 1970's, the Center's growing involvement in space science research spawned a host of specialized facilities within the existing labs. The breadth and depth of expertise here now may be unsurpassed by any other single research institution. As a result of this resident technical competence, Marshall has evolved into a highly-respected multidisciplinary research center.



The mysteries of the universe

UNITED STATES DEPARTMENT OF
COMMERCE
NEWS
GAITHERSBURG MD 20899
NATIONAL BUREAU OF STANDARDS

The commercial uses of space

A Glimpse of the Future

Now that people have crossed the border into space, there is no turning back. We have only begun to observe and explore the universe, and human curiosity demands more. Inexorably science and technology will move into space, because it is a uniquely favorable environment for research.

Space is an excellent vantage point for both astronomical and terrestrial observations, and the effects of gravity are negligible there. Thus, space offers opportunities to answer questions and do experiments that are impossible on Earth. The temptation is irresistible.

In the few years since space has become accessible, there has been a veritable explosion of knowledge. Whole new disciplines, such as X-ray astrophysics and solar-terrestrial physics, were born, and with each new

nstrument or spacecraft the pace of discovery quickens. Who can guess what discoveries are yet to be made?

One can predict that in the next 25 years, the growth of knowledge will be even more phenomenal. If there were only one major new telescope, for example, the advance would be significant, but entire families of space telescopes are planned. What does it really mean to look 7 times farther at much dimmer objects than now possible? What will we see?

As observations are perfected along the spectrum from radio emissions to infrared, visible light, ultraviolet, X-rays, and gamma rays, what will we find? Something stranger than black holes and quasars? The edge of the universe? Signs of intelligent life somewhere else? By placing sensitive telescopes and observers above the hazy atmosphere that obscures our view outward, we take the risk of discovering far more than we have expected. Unimagined discoveries resulted from our first tentative steps in space; that trend should continue, becoming even more dramatic, as we establish a permanent presence in space.

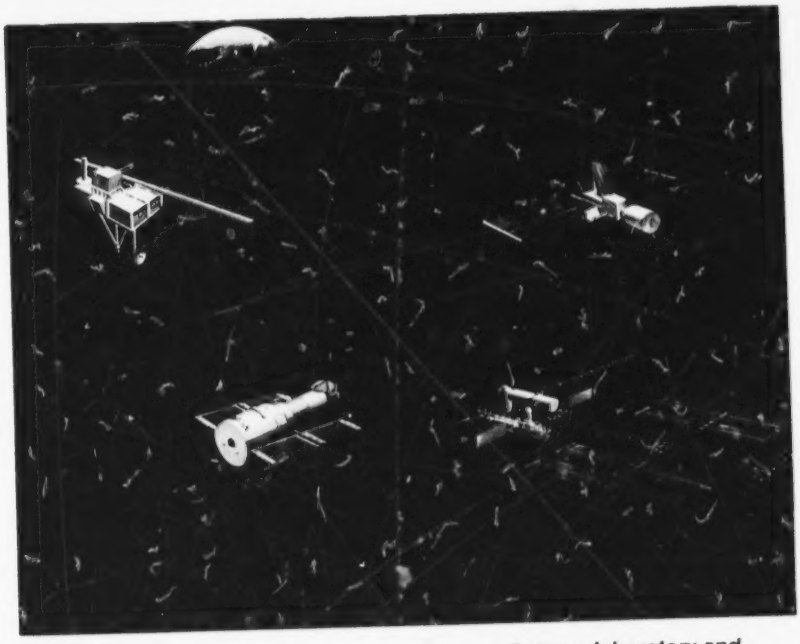
We are just beginning to look back upon Earth with the precise scientific tools and techniques that reveal the distant universe in detail. Viewed from space, Earth's atmosphere is thin, complex, dynamic, influenced by radiation from remote quarters. What surprises may shake our comfortable familiarity with the terrestrial environment, which we have barely begun to understand?

The advantage of microgravity is equally tantalizing. In space it is possible to examine fundamental biological and physical processes under conditions that cannot be achieved on Earth. In space, living organisms can be studied apart from the influence of gravity to understand just how it is that life functions, and sometimes malfunctions, on Earth. Likewise, inanimate processes can be observed without the interference of gravity to understand the properties and behavior of matter or to test physical laws.

Three decades ago, no one knew whether or not a human being could survive in space. No one knew how fluids, whether blood or propellants, behaved in weightlessness. No one knew about quasars and exotic celestial objects, or about the Van Allen radiation belts and the Earth's magnetosphere.

Although many questions have been answered, even more have been raised. Today's space scientists at Marshall are challenged to find answers. They have the opportunity to pursue their research in space, either by controlling sophisticated instruments from the ground or by actually working in an orbital laboratory. The rewards of orbital research undoubtedly will increase with advances in data and communications technology, making today's flood of information look like a mere trickle.

Science and technology move in parallel, one asking questions and the other providing ways to answer them. Today's questions are beginning to be answered with the aid of new instruments and spacecraft. Tomorrow's questions will emerge as the remarkable new space observatories and laboratories become operational. The "book of knowledge" will not close any time soon. The challenge now is to continue the quest for knowledge with all available, and all imaginable, resources. ■

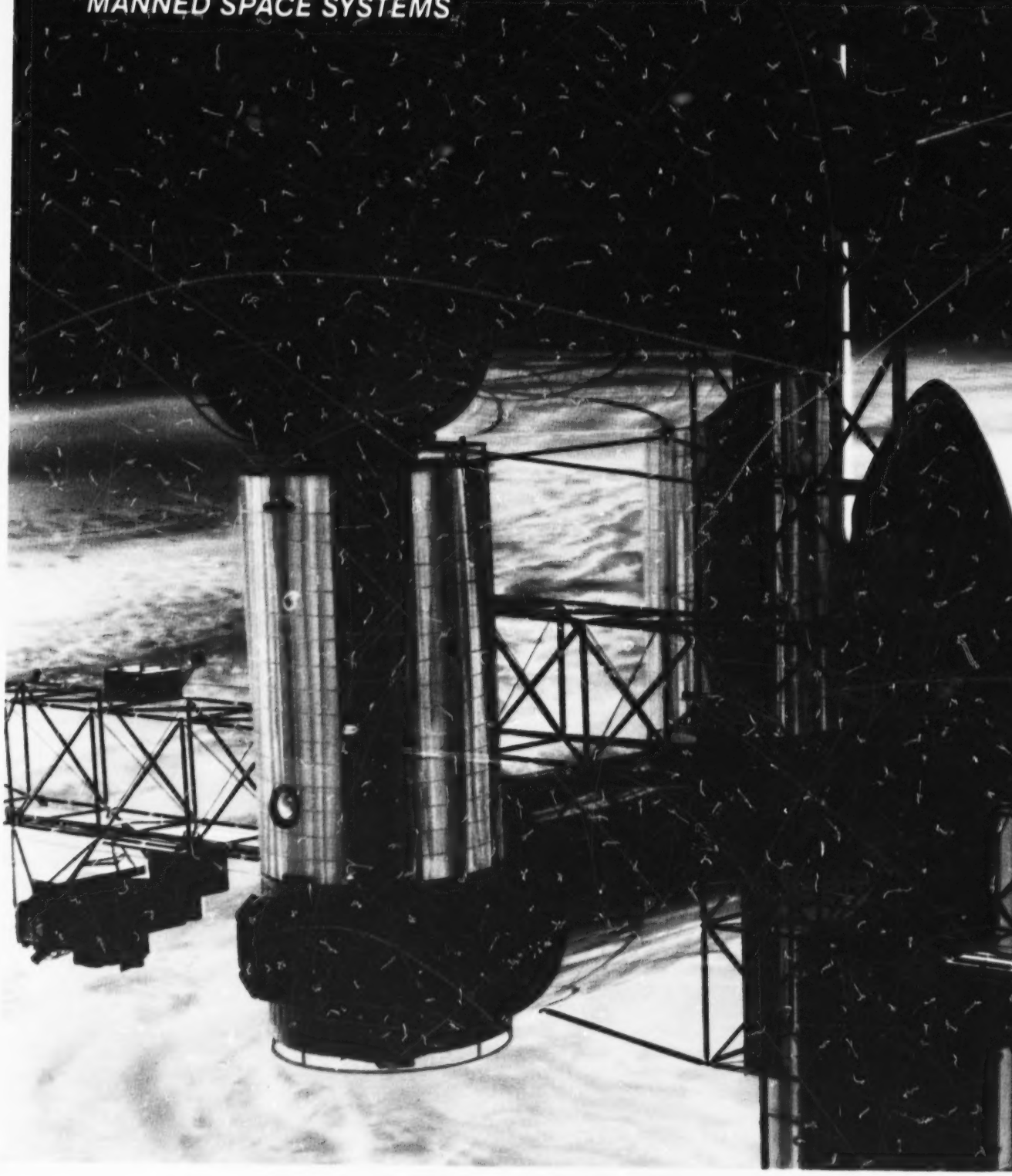


Space – laboratory and observatory site for the future

"With the great tasks before us, there is a continuing need for scientists and engineers dedicated to giving man the means for reaching the stars."
Dr. W. R. Lucas

A PERMANENT PRESEN

MANNED SPACE SYSTEMS



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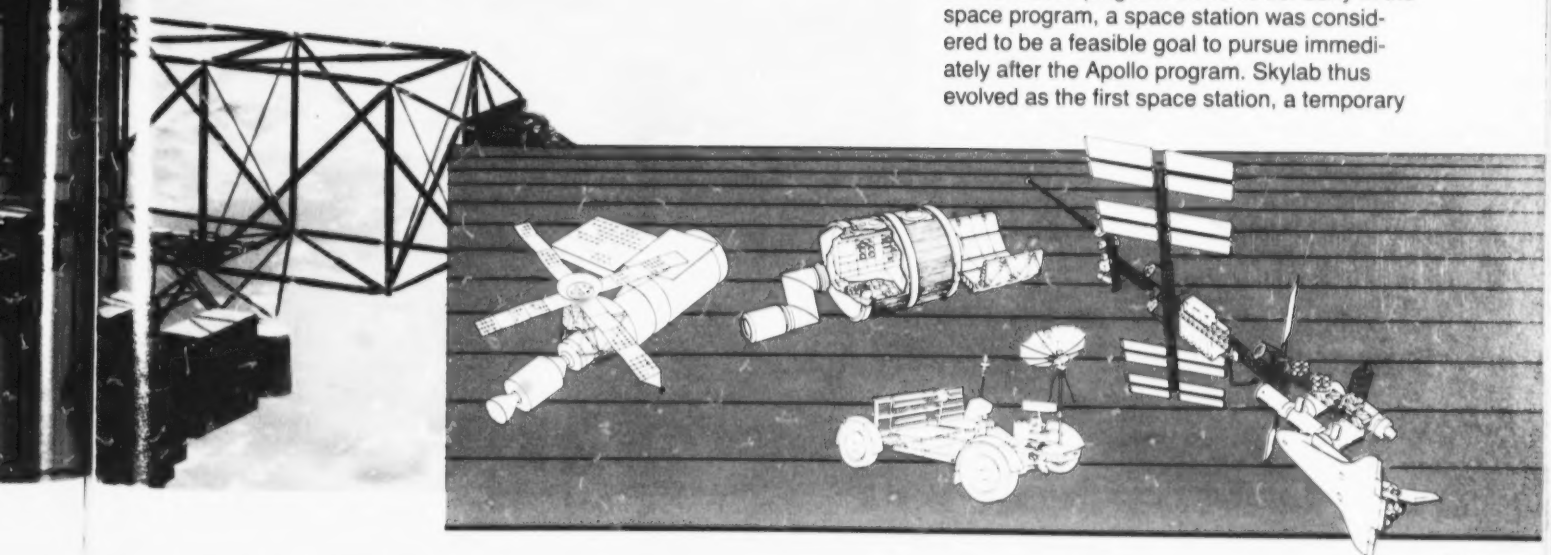
Besides launch vehicles and space science research, Marshall Space Flight Center has a distinguished record of achievement in the development of manned systems, the astronauts' work places in space. Since Apollo, NASA has sponsored the very successful Skylab and Spacelab programs that demonstrated how readily and productively people can live and work in space. Marshall played the leading project management and engineering role for the agency in these ventures, thereby developing capabilities unforeseen in the Saturn era. Marshall also was involved in smaller scale manned projects, such as the Lunar Roving Vehicle and the international Apollo-Soyuz Test Project.

As the Center celebrates its twenty-fifth anniversary, the most challenging new program is the development of a Space Station, a permanent manned habitat in Earth orbit. Within the agency, industry, and the scientific community, both in the United States and abroad, there is a flurry of activity to define Space Station architecture, capabilities, and uses. A casual observer might think, mistakenly, that this initiative really is new, that designers and engineers, scientists and managers are starting from scratch to formulate a residence in space. Actually, many people at Marshall already are veterans in Space Station planning.

The concept of a space station is older than NASA itself. To the early rocket pioneers, a space workshop or colony was a major reason for developing launch vehicles. Early in the space program, a space station was considered to be a feasible goal to pursue immediately after the Apollo program. Skylab thus evolved as the first space station, a temporary



A PERMANENT PRESENCE

precursor to a permanent presence. About 1970, however, NASA decided to postpone construction of a permanent space station until a suitable space transportation system was in service.

In the interim, the Shuttle could serve as a short-term space station by carrying a scientific research facility, Spacelab, on missions of a week or more. Like Skylab, Spacelab is a valuable preparation for a permanent space station; experience in hardware development and human engineering for these work environments in space is directly applicable to a larger-scale effort. When President Ronald Reagan approved Space Station development in 1984, NASA responded quickly and confidently.

The Space Station is the next logical step in the exploration and utilization of space. Marshall Space Flight Center has responsibility for definition and preliminary design of several major elements of the prospective Space Station and is also supporting development of some elements managed through other NASA centers. As it addresses these new challenges, Marshall will draw from its bank of past experience in manned systems. For the foreseeable future, the Center's primary mission is to develop a permanent work place in space. The Space Station requires a magnitude of effort and commitment to excellence comparable to that of the Saturn and Shuttle endeavors.

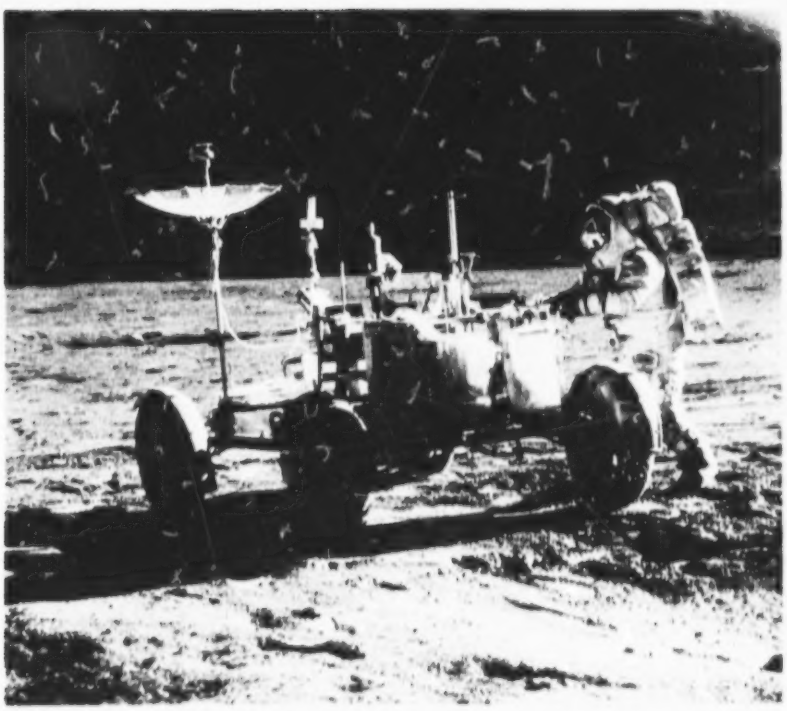
Lunar Roving Vehicle

Marshall moved from launch systems into manned systems via a Lunar Roving Vehicle designed to transport astronauts and materials on the moon. As time drew near for the manned lunar landings, NASA decided to provide a vehicle that would extend the astronauts' range of exploration and their ability to carry equipment and lunar samples. By 1969, Marshall was responsible for the design, development, and testing of the new article. Boeing was selected for contract award, and work began in 1970 with flight expected the following year.

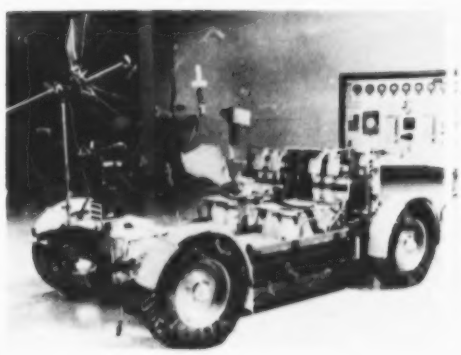
What a contrast the lunar rover was to the towering Saturn vehicles! It was a fragile looking, open-space vehicle about 10 feet long with large mesh wheels, antenna appendages, tool caddies, and cameras. Powered by two 36 volt batteries, it had four ¼ hp drive motors, one for each wheel. The peculiar vehicle was collapsible for compact storage until needed, when it could be unfolded by hand.

Marshall engineers tackled this new project with relish; inventing a "car" for drivers on the moon was as appealing to a grown-up imagination as to a child's. Personnel from the Center's laboratories contributed substantially to the design and testing of the navigation and deployment systems. In fact, the backup manual deployment system developed by Marshall proved more reliable than the automated system and became the primary method of deployment.

The rover was designed to travel in forward or reverse, negotiate obstacles about a foot high, cross crevasses about two feet wide, and climb or descend moderate slopes; its speed limit was about 14 km (9 miles) per hour. To assist in development of the navigation system, the Center created a lunar surface simulator, complete with rocks and craters, where operators could test drive the vehicle. The simulator also was used during the mission as an aid in responding to difficulties.



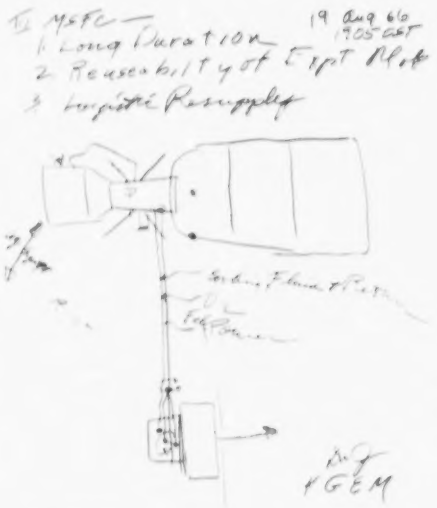
Marshall-designed vehicle in use on the moon



Lunar rover (on support stand) at MSFC

A lunar rover was used on each of the last three Apollo missions in 1971 and 1972 to permit the crew to travel several miles from the landing craft. Outbound, they carried a load of experiments to be set up on the moon; on the return trip, they carried more than 200 pounds of lunar rock and soil samples. The vehicle performed safely and reliably on each excursion and enhanced the astronauts' work efficiency. It handled as well and steered as easily on the moon as on Earth.

In addition to the technical achievements, the lunar rover was a managerial success with an unusually short development cycle. More than any prior work, this project gave Marshall insight into human engineering considerations for space hardware on manned missions. Although the vehicle was not as complex as a habitable laboratory, it was in effect a small work place with some similar crew requirements. Thus, the rover project provided valuable crew systems and mission support experience for later projects. During the lunar rover work, the Center also used realistic new simulation techniques for testing equipment and procedures. Simulation would soon be used extensively for design evaluation, hardware checkout, crew training, and mission support activities in other manned projects.



Early concept of Skylab workshop with observatory on a long cable

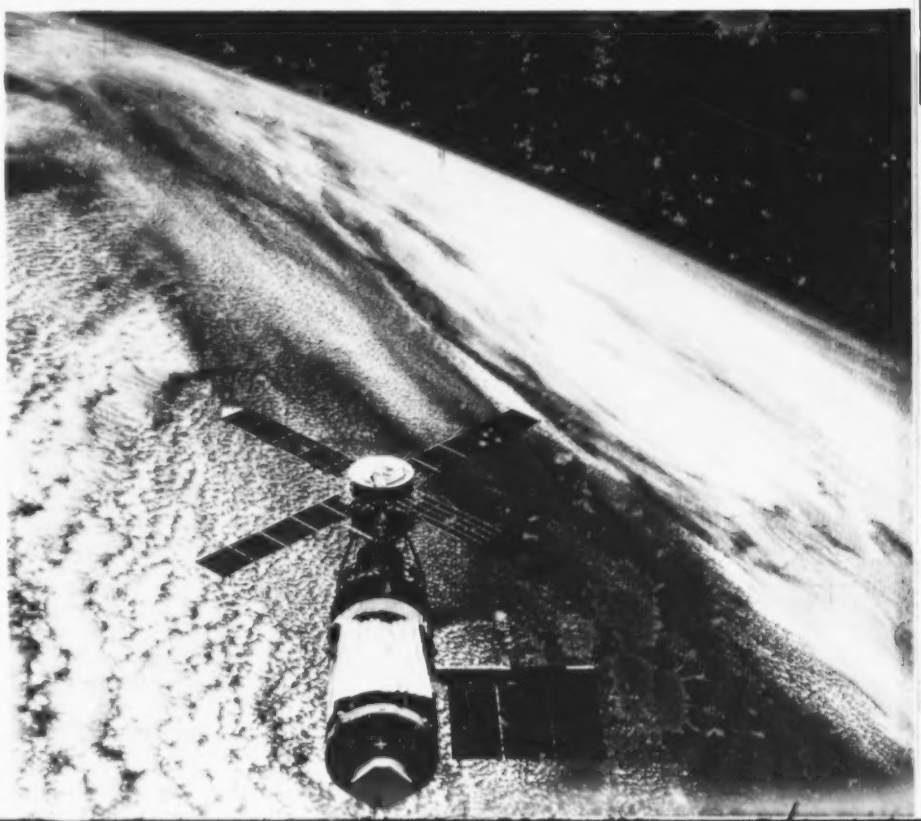
Skylab

The idea that ultimately became Skylab first surfaced in 1962 as a proposal to convert a spent Saturn upper stage into an orbital workshop. Soon, planners in Huntsville were evaluating the feasibility of rendezvous with a cast-off stage, which would then be purged, pressurized, and outfitted with scientific equipment. In 1965, NASA established the Apollo Applications Program to extend the use of Apollo and Saturn hardware; a few months later, the agency authorized a design study for a spent stage orbital workshop and named Marshall Space Flight Center as leader of the project.

For the next three years, Marshall wrestled with configuration and planning. Several launch schedules were announced for an ambitious program of multiple workshop facilities. In 1968, Marshall proposed an alternative to the original "wet" workshop concept of refurbishing a spent stage in orbit; instead, a fully equipped "dry" workshop could be launched as a complete unit, ready for occupancy. In 1969, NASA approved this concept and contracts were revised accordingly. The following year, the Apollo Applications Program and

"Instruments continue to be indispensable in the exploration of space. But man has proven himself irreplaceable."
Dr. Wernher von Braun

Skylab orbital workshop and attached observatory



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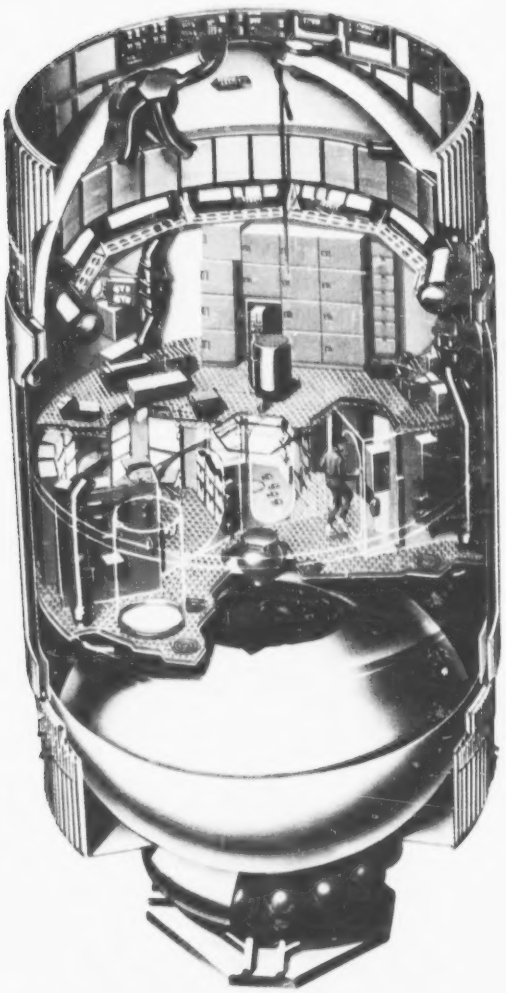
Saturn workshops were officially renamed Skylab.

The eight-year Skylab project was Marshall's most comprehensive mission involvement to date. The Center was responsible for early definition studies, provision of the launch vehicles, development of the various manned modules, development and assembly of the scientific payload, systems engineering and integration, development of crew procedures, and provision of real-time mission support. People all around the Center participated in Skylab planning, hardware activities, simulations, and support efforts during the mission. Skylab was the largest spacecraft and the longest-manned mission in the space program. The Center's existing skills were well exercised in the Skylab era, and new capabilities grew in response to the unusual technical and managerial challenges of developing the nation's first space station.



Floor plan of Skylab workshop and living quarters

A Work Place in Space

The basic elements of Skylab were defined fairly early, and some of the units were ready for testing when the configuration decision was made in 1969. Skylab was conceived as a cluster of five modules: an Orbital Workshop, Instrument Unit, Airlock Module, Multiple Docking Adapter, and Apollo Telescope Mount. The cluster was launched by a two-stage Saturn V with the workshop itself as a modified third stage. Marshall was responsible for the development and integration of all these hardware elements and for providing the launch vehicles a Saturn V for Skylab and Saturn IBs for three Apollo spacecraft and crews. These vehicles were brought out of inventory and refurbished for the Skylab missions.

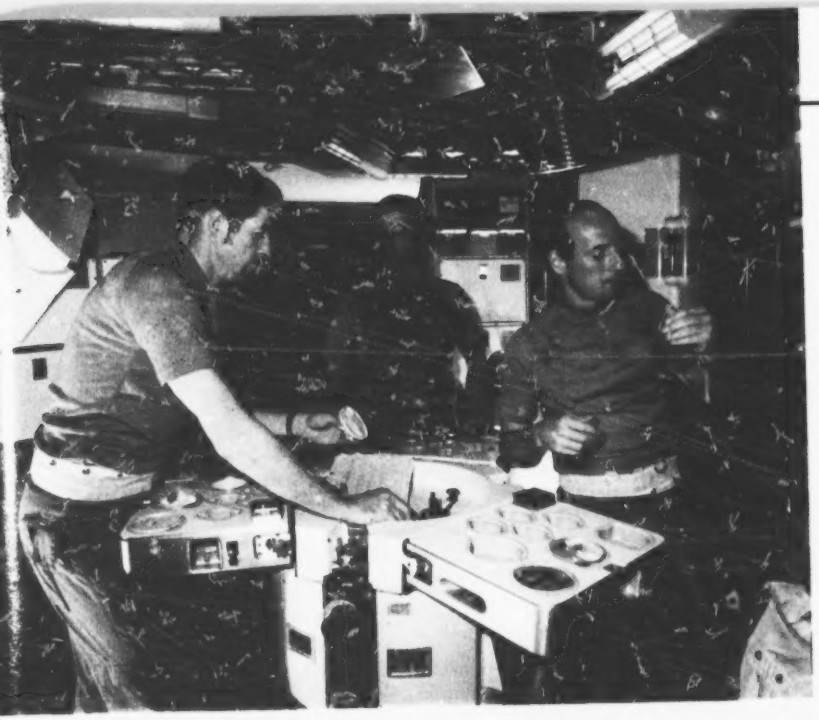
Marshall worked closely with McDonnell Douglas, the prime contractor for the workshop unit, to convert a Saturn IVB stage into a habitable module containing crew living quarters and support systems as well as some experiment area. The huge forward tank formerly used for liquid hydrogen was partitioned, equipped with utilities, and furnished to make an area about the size of a five-room house where three-member crews could live comfortably for one to three months.

Many new devices were developed for the comfort and well being of the crew in their orbital home. Marshall engineers tackled the problems of zero-gravity showers and toilets, sleeping bags, exercise equipment, and kitchen facilities. They were also involved in developing and selecting materials used in crew quarters and as protective thermal coatings; such features as outgassing, contamination, toxicity, and flammability were carefully evaluated in view of long-term human occupancy.

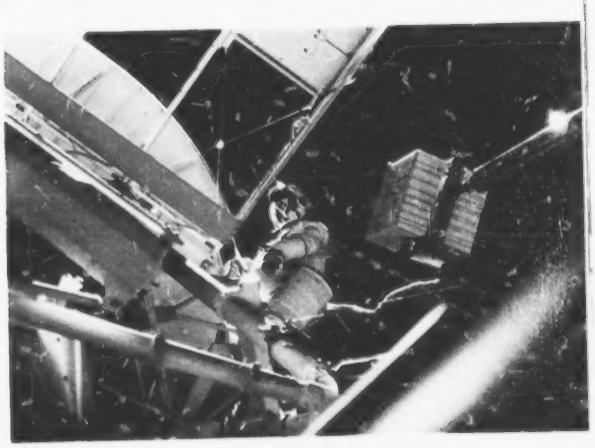
The Instrument Unit, like that on the Saturn launch vehicles, provided certain guidance, control, and sequencing commands. After launch, it was used for deployment of the solar arrays mounted on the workshop and for a telemetry link between Skylab and the ground.

The Multiple Docking Adapter was a docking facility for the Apollo Command and Service Module, which ferried crews and supplies to Skylab. It also served as a passageway to the workshop and as a laboratory that contained most of the experiment equipment and the control and display console for the Apollo Telescope Mount. Marshall designed and built the structure for this unit in-house.

The Apollo Telescope Mount was an observatory housing eight scientific instruments for detailed study of the sun. The



Meal time in the Skylab galley



Working outside to change film in observatory instruments

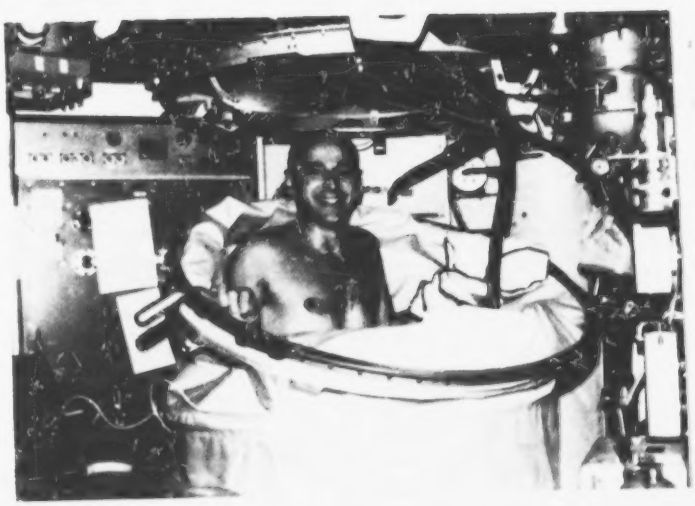
observatory was mounted to the docking adapter and operated by the crew from a workstation there. Marshall built some parts of the mount in-house and worked closely with several contractors to develop a very precise attitude control and pointing system that served the telescope and the entire Skylab cluster. The Center provided a simulation facility for tests of the attitude pointing control system hardware and software and for real-time mission support. Marshall also supervised systems integration of the observatory and its instruments.

Finally, the Airlock Module served as the link between the docking adapter and the workshop. This module housed the control systems for Skylab's utilities – environmental and thermal control, power distribution, communications and data handling. It also provided the hatch, airlock, and equipment for extravehicular activity, when crew members went outside to change film in the telescope or do other maintenance and repair work. McDonnell Douglas fabricated the module with close Marshall involvement in design, development, and test activities.

To support the hardware development effort, Marshall created two full-scale Skylab mockups for detailed engineering analyses and simulations. A one-g "shirtsleeve" mockup resided in Building 4619 and an underwater mockup was installed in the Center's new Neutral Buoyancy Simulator, a 40-foot deep water tank, completed in 1968, where the effects of microgravity (weightlessness), could

"With Skylab we are not concerned primarily with flying a spacecraft. We are concerned with the important aims of living and working in Earth orbit and conducting the experiments that will eventually lead to many beneficial results."

Dr. Eberhard Rees, 1970



A shower in space

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be simulated. For several years, these two mockups became the focus for manned systems test activities, and they were visited repeatedly by astronauts. In 1969, the Center began neutral buoyancy simulations of Skylab extravehicular activity; these practice sessions tested tools and procedures for maintenance and repair tasks associated with the Apollo Telescope Mount. In 1970, the Center hosted a week-long crew station review by astronaut teams using both mockups.

Practicing film change-out underwater at MSFC

Developing a solution to Skylab's thermal shield problem

By the time of launch in May of 1973, Marshall people knew Skylab inside and out, and they were well prepared to support the nine-month mission. Personnel moved into the Huntsville Operations Support Center (HOSC) for real-time flight support, and mission task centers, called "war rooms," were set up in Marshall's laboratories to assist the HOSC team in resolving any problems that might occur in flight. During the three manned periods, these support groups were fully staffed for around-the-clock operations; in the unmanned intervals, a skeleton staff maintained watch. This mission support activity was much more extensive than the launch support normally provided by the Center and the standby support during excursions of the Lunar Roving Vehicle. To everyone's surprise, Marshall's resources for mission support were severely tested immediately after launch.

Quick Response to a Problem

Within an hour of launch on May 14, 1973, there were ominous signs of trouble aboard Skylab. Although the spacecraft had been delivered easily to its intended orbit, the micrometeoroid shield sun shade and solar arrays failed to deploy as planned. As a result, the Skylab workshop was rapidly heating to intolerable temperatures (almost 200° F) and operating on a fraction of the necessary power. These conditions threatened disaster to the workshop and jeopardized the manned mission scheduled for launch the next day.

Marshall personnel immediately regrouped into a crisis management organization to stabilize the thermal condition of Skylab and to develop repairs. The manned mission was postponed and for the next 11 days Marshall, its contractors, and NASA personnel at other centers concentrated on saving Skylab. All the resources of the Center were available to the ten laboratory task groups already in existence and to the various ad hoc groups formed in response to the crisis. Technical and managerial personnel shifted to 12-hour duty cycles.

and some people worked for days at a time.

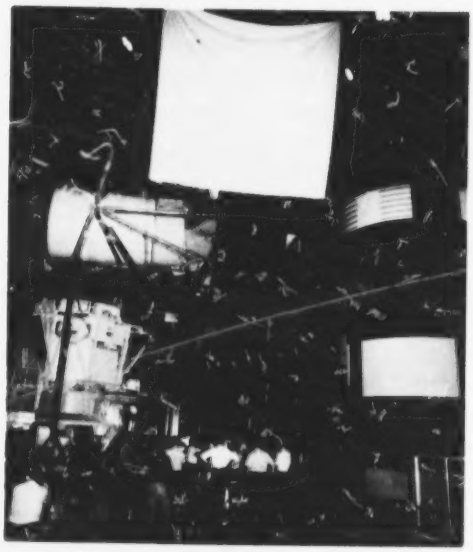
The mission support teams faced three major problems and a host of smaller ones caused by the failures. The most urgent matter requiring immediate attention was the overheating problem. Attitude control and thermal experts had to find a rapid solution to reorient Skylab and establish a better thermal balance. They were hampered, of course, by the need to keep the functional solar arrays of the Apollo Telescope Mount pointed at the sun. In the first hours of the crisis, they experimented with various maneuvers to shade the workshop but maintain the limited power supply. Before long, they were able to implement a satisfactory solution that preserved Skylab until the rescue crew arrived on May 25.

The next major problem was to determine the extent of damage on Skylab and devise corrective repair operations. Virtually every element of the Marshall Center, with hearty support from the other NASA centers, became involved in an intense effort to fix Skylab. Data analysis suggested that the micrometeoroid shield and one solar array had been ripped off during launch and that the second solar array was tangled up in debris and only partially deployed. Since the exact condition of these elements was unknown, engineers had to rely on calculations and simulations to estimate the nature of the problem and the best solution.

Over the next several days, Marshall considered a variety of repair options, discarding some and pursuing others under tremendous time pressure. Eventually, three methods were developed, tested, rehearsed, and approved. Marshall was intensely involved in all three – a parasol sunshade, a twin-pole sunshade, and a set of metal cutting tools for freeing the jammed solar array – but had the lead role in developing the tools and the twin-pole sunshade, a large protective sail.

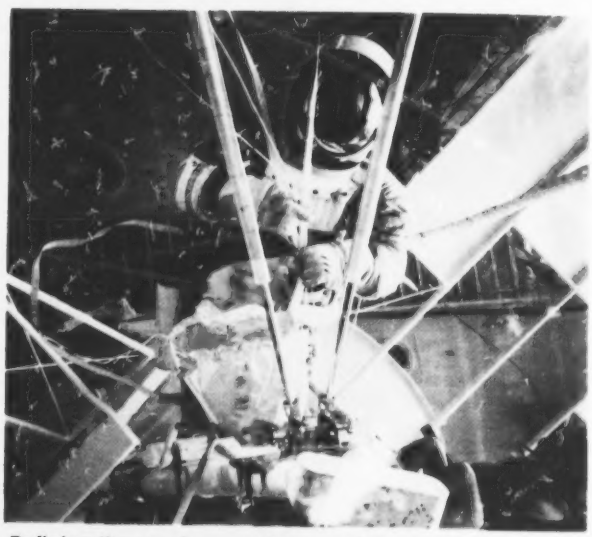
Designing the hardware and crew procedures, demonstrating the method, and fabricating the equipment occupied hundreds of people for more than a week. Everything about the effort was a challenge under duress. Not only must it be the most practical solution to the thermal problem but also it must survive structural and dynamic stresses, stand up to intense solar radiation, meet stringent crew safety requirements, be compact and lightweight, and be available as soon as possible. What would normally be months of effort was condensed into a few days.

Devising tools and procedures to release the jammed solar array also provoked a flurry



Testing the twin-pole sunshade at the Skylab mockup in Building 4619

"In my opinion, the finest accomplishment of Skylab was the demonstration of the uniqueness of man in space in solving problems and overcoming obstacles in the face of extreme adversity."
Dr. Rocco Petrone



Refining the repair procedures underwater in Marshall's Neutral Buoyancy Simulator

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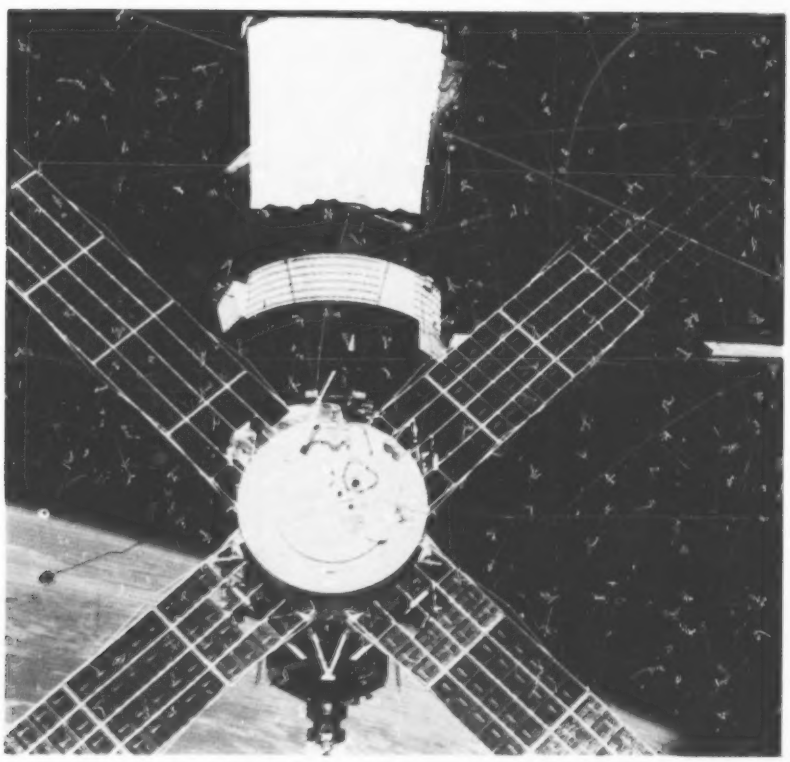
of activity. Again the engineers who could not "see" the problem had to solve it by the safest, most practical methods. Standard off-the-shelf shears and saws were modified and tested for anticipated use.

The third major problem was degradation of the interior environment of the workshop, an unknown factor of great concern for crew safety. The prolonged, extraordinary heating of the module might have caused interior insulation and adhesives to deteriorate and release toxic gases. Marshall's materials scientists undertook a thorough evaluation of this potential problem and worked with other systems engineers to define purge procedures for the habitable module. Even as they were testing the materials for outgassing, this group was also embroiled in testing various candidate sunshade materials.

During the Skylab crisis, Marshall's many human and physical resources were admirably demonstrated. The Neutral Buoyancy Simulator was a special asset that proved its worth as a test environment again and again. Trial runs underwater revealed a number of difficulties and led to speedy recognition of more effective solutions. Experts around the Center – in the laboratories, machine shops, and management offices – and from Marshall's contractors united in a multidisciplinary team response to the emergency. Morale remained high despite the taxing work schedule.

The Skylab crew and their repair kits were launched just 11 days after the incident. After docking with Skylab, the crew successfully deployed the parasol sunshade through an airlock the next day and, as the temperature dropped, began to activate the new space station. The interior environment proved safe and contamination-free, though still a rather warm work place. On the ground, Marshall's teams continued to perfect techniques for the major repairs. In a daring though well-rehearsed maneuver, the solar array was freed on June 7 by the crew working outside Skylab with a technique developed at Marshall. After that the Skylab mission settled into a fairly nominal routine, much as planned.

The parasol sunshade proved effective for the first manned period on Skylab but had to be replaced by the Marshall sail during the second occupancy because interior temperature was increasing again. During the interval between missions, Marshall engineers and NASA astronauts practiced and improved the repair technique during frequent neutral buoyancy simulations. More than any other program, the successful Skylab recovery operations clearly demonstrated the value of manned space flight.



Marshall's Skylab solar shield installed in space

Skylab Legacies

Skylab was the first American space program wholly dedicated to scientific research. Conceived as a laboratory for simultaneous research in several disciplines, Skylab contributed to solar physics, astronomy, biomedical science, materials science, Earth observations, and basic technology. Marshall played an important part in this unprecedented scientific venture, both before the mission by managing the development and integration of the experiments and later by supporting their operations in flight.

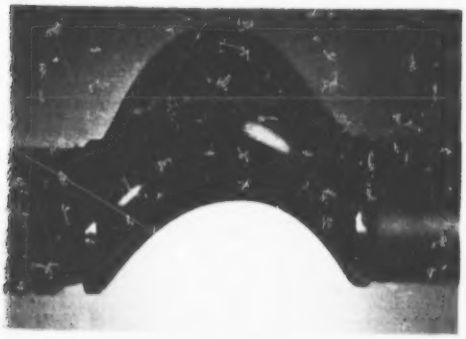
Skylab operated in orbit from May 1973 through February 1974. It was occupied for three periods for a total of 171 days. During that time, the advantages of doing research in space with a very capable scientific crew were convincingly demonstrated. Skylab results included significant discoveries in all the experiment disciplines and far more data than anticipated. Solar observations revealed unsuspected features and events, dramatically altering our understanding of the sun's structure and activity. Skylab offered the first opportunity for a sustained investigation of the

human body in space; a plethora of biomedical experiments and measurements provided new insight into physiological adaptation to weightlessness. The first set of materials processing experiments in space produced intriguing results on crystal growth, solidification of alloys, and fluid behavior in microgravity. The Earth resources observations produced detailed new information from the unique vantage point of space by a variety of remote sensing techniques, and astronomical observations also were successful. Skylab opened the era of comprehensive scientific research in space.

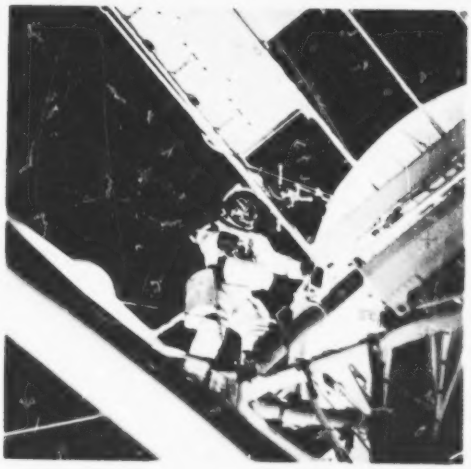
Skylab also proved the operational concepts for long-term habitation in space and particularly demonstrated how capably and productively people could work in this new environment. It also demonstrated the value of a human presence for maintenance and repair to extend the useful life of systems in space. The orbital servicing and repair activities gave new insight into both design and operational considerations for future missions.

For Marshall and for NASA at large, Skylab represented a transition from short manned flights to long-term manned orbital operations and from single-purpose spacecraft to multipurpose space stations. The Marshall Center developed strong new capabilities for science payloads and mission support operations. After Skylab was vacated, it remained in orbital stowage for several years in anticipation of future visits. Instead of returning to Skylab, however, NASA pursued its direct descendant – Spacelab – a Shuttle-borne research facility. Marshall was destined to play an even greater role in this new program.

In the interim between the two manned laboratory projects, Marshall was preoccupied with various scientific projects and with adjusting to manpower and budget cuts. The unusual Apollo-Soyuz Test Project bridged the period between Skylab and Spacelab.



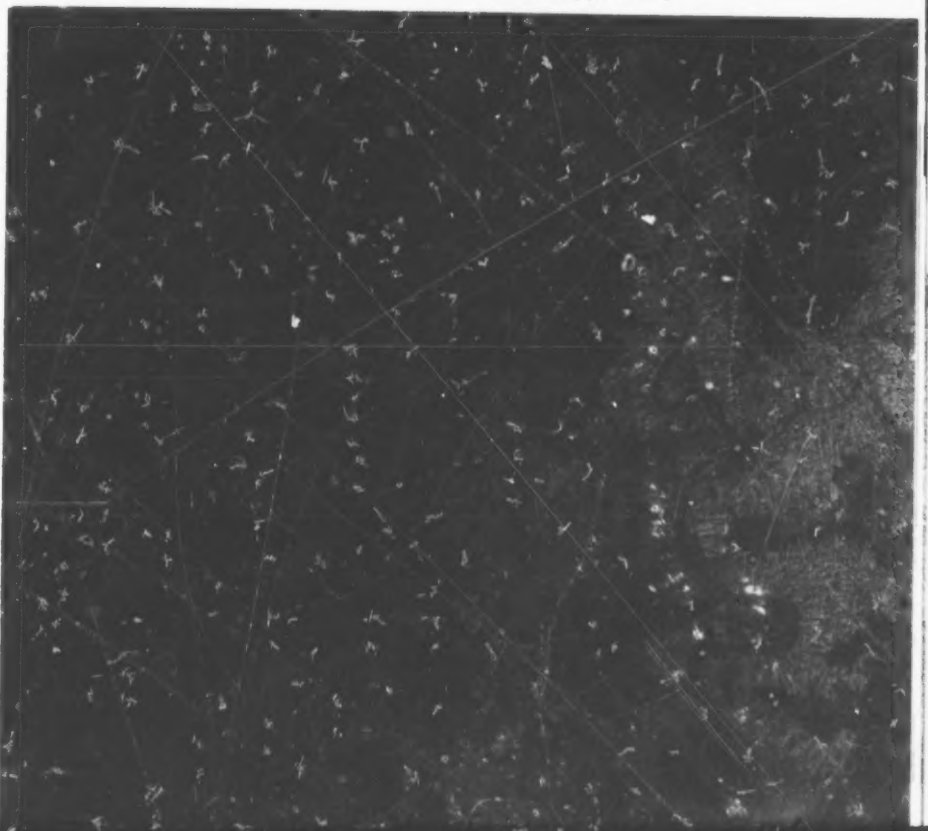
Crystal growth and materials processing research on Skylab missions



Maintenance and repair tasks outside the workshop

Microgravity research inside the orbital laboratory

Skylab Earth resources observations (infrared image of the lower Mississippi River)



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Apollo-Soyuz Test Project

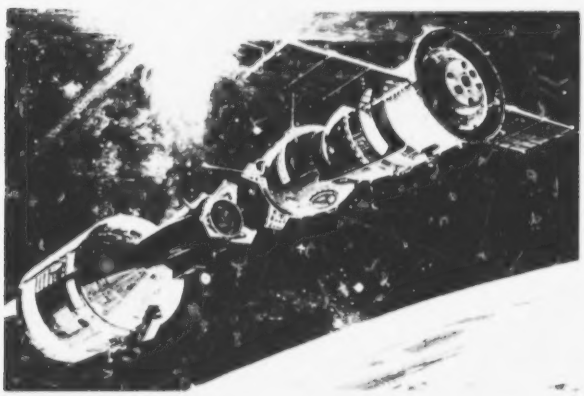
The period between the last Skylab mission (1973/74) and the first Shuttle flight (1981) was a quiet one for manned spaceflight. Only one manned mission was launched – the Apollo-Soyuz Test Project in 1975. This mission marked both the last use of a Saturn launch vehicle and the first cooperative, international manned flight. The purpose of the mission was to demonstrate rendezvous and docking for joint ventures in space. This capability might eventually be used for international rescue missions and for mutually beneficial science and engineering activities. Marshall Space Flight Center participated in preparing for this historic mission.

Overtures toward a joint American-Soviet mission were made in 1968, followed by talks between representatives of both space agencies over the next few years. Marshall personnel served on the American delegation that met with Soviet personnel in the United States and in Moscow. In 1970, two Soviet cosmonauts visited the Center on a tour of NASA facilities. At a 1972 summit meeting, President Richard Nixon and Premier Alexei Kosygin signed a five-year cooperative agreement and set a target mission date in mid-1975.

The major challenge of the Apollo-Soyuz Test Project was to make two quite different space systems compatible enough to link up in orbit. This required design of a common docking adapter to join the two spacecraft and enable crew members to move from one module to the other for their "handshake in space." Coordination of rendezvous guidance systems and flight techniques also was necessary.

Although there had been early consideration of a Skylab-Soyuz mission, which would have meant heavy Marshall Center involvement, the final decision was to dock with an Apollo spacecraft. Thus, Marshall's primary role was to provide the launch vehicle. A Saturn IB that had spent more than five years in storage was refurbished and performed flawlessly. The Center also provided several of the scientific experiments and a Multipurpose Electric Furnace similar to one flown on Skylab for processing material samples.

The test project successfully demonstrated the new docking capability, but there were no subsequent missions. NASA's next international venture was with colleagues in Western Europe rather than the Soviet Union.



Concept of the rendezvous of American and Soviet spacecraft

Apollo-Soyuz: historic handshake in space

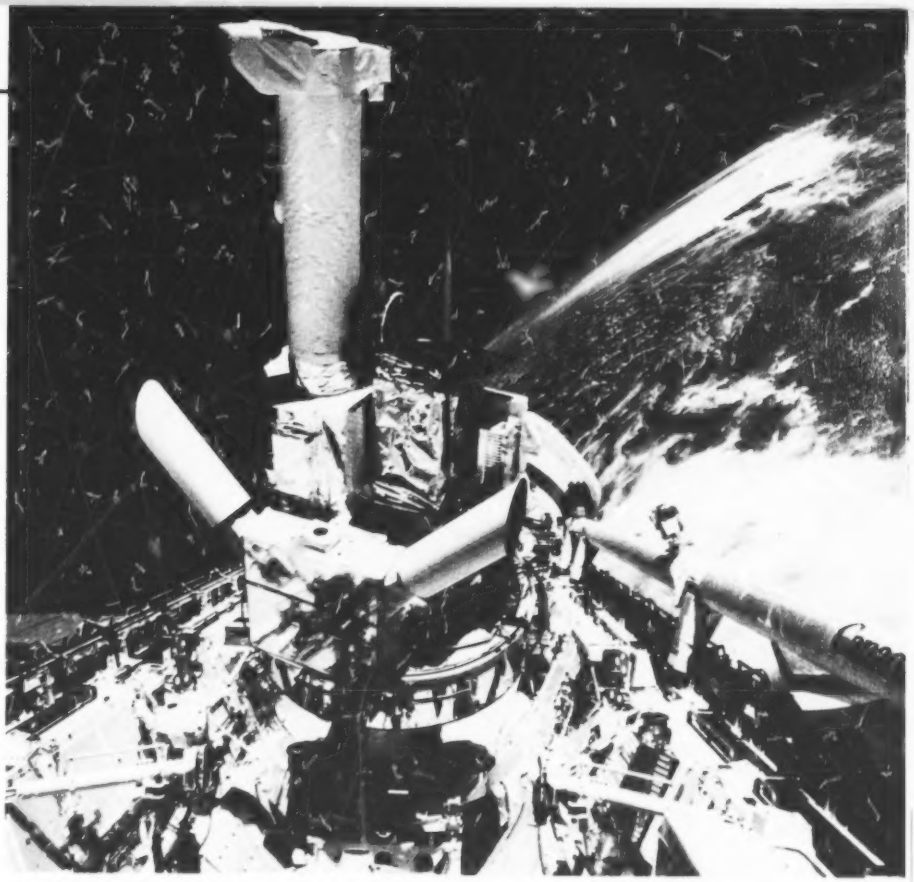
First international meeting in space

Spacelab

In 1969, Europe was invited by the United States to participate in the post-Apollo space program. The European Space Research Organization, which later became the European Space Agency (ESA), agreed in 1973 to develop a manned laboratory as Europe's contribution to the new Space Transportation System. What became Spacelab was conceived originally at Marshall as a "sortie can," a modular laboratory system to be periodically installed in the Space Shuttle for week-long science missions. A handful of selected NASA engineers from the Marshall Center interacted with the Europeans to initiate the Sortie Can program, later named Spacelab. The work of this small group established an important link for international space programs. The resultant Spacelab program was a cooperative venture between ESA and NASA; the European Space Agency designed and manufactured Spacelab with NASA's support in design and design requirements, and NASA now operates it on Shuttle missions.

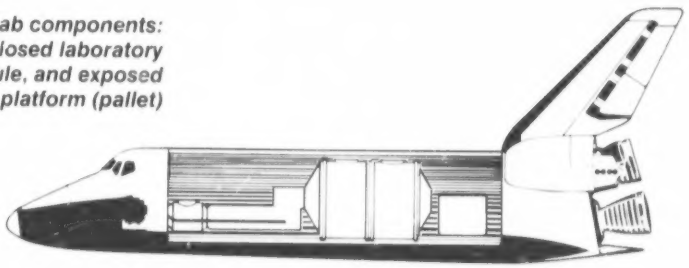
In the busy period of development between the 1973 decision and the first Spacelab flight in 1983, Marshall Space Flight Center assumed program management responsibilities for monitoring and supporting the ESA activity; developing related flight equipment, software, and ground support facilities; and directing the first missions. For the better part of a decade, the Center's resources were enlisted in the related Spacelab and Shuttle projects. While hardware development was in progress, NASA and ESA engaged in a parallel activity of developing the first Spacelab payload; experiments and crew members for the initial mission were provided by both agencies. Between 1972 and 1977, the two partners conducted a joint airborne program, a trial run called ASSESS, to work out their mission management and operational concepts. Furthermore, Marshall began planning ahead to subsequent missions.

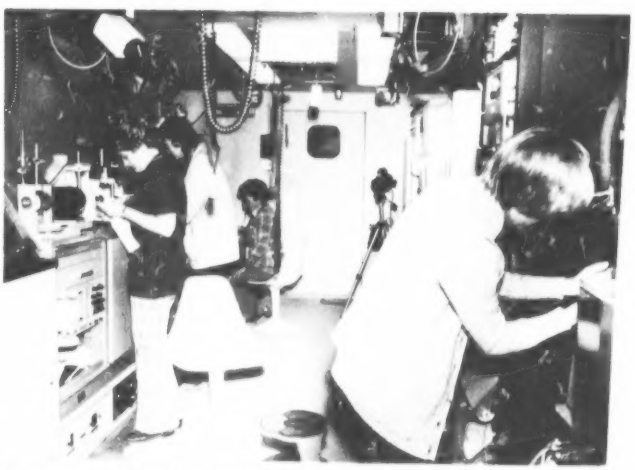
Technically, scientifically, and managerially, the Spacelab program broke new ground in international cooperation for manned spaceflight. The Marshall Center successfully managed this largest-ever program of shared responsibilities. Although the development effort and first missions are now history, Spacelab continues to be a major commitment at Marshall as Spacelab is used again and again for research in space.



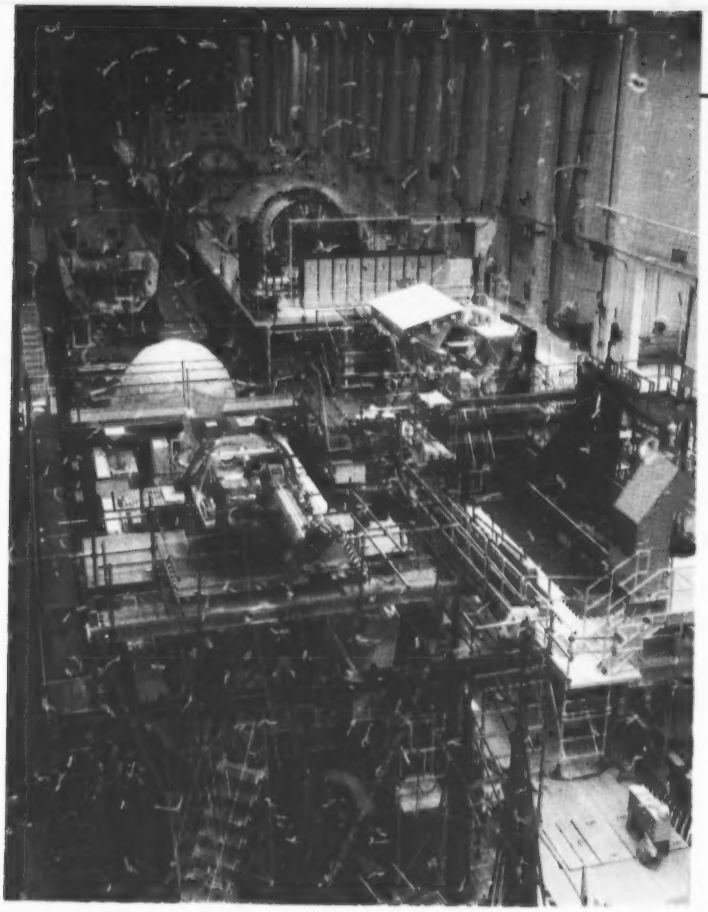
Pallet-mounted Instrument Pointing System, first used on Spacelab 2 mission

Spacelab components: tunnel, enclosed laboratory module, and exposed platform (pallet)

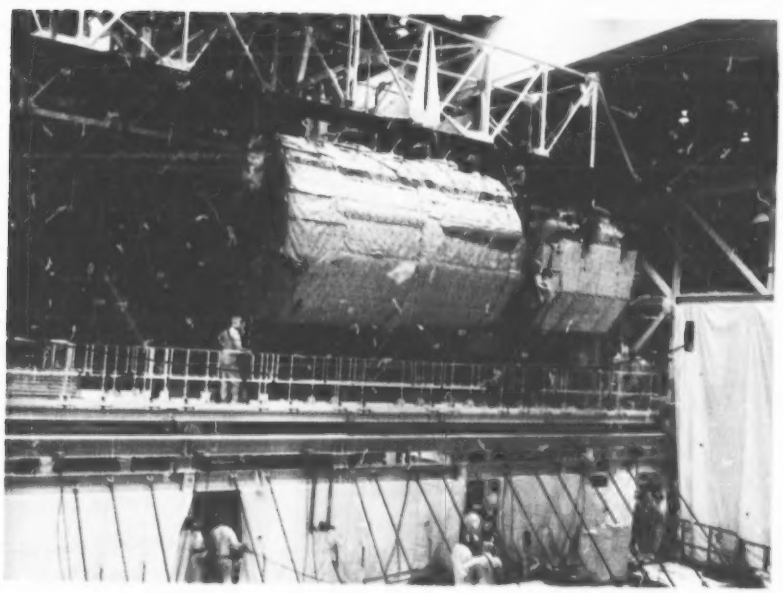




Concept verification testing of Spacelab materials science experiments in MSFC's General Purpose Laboratory



Spacelab payload integration for several missions at the Cape



Spacelab 1 module and pallet ready to be installed in the Shuttle

Developing Spacelab

Although ESA bore primary responsibility for designing and manufacturing Spacelab, Marshall's role as the lead NASA center required broad participation in all technical and managerial activities. The international scope of the program was unprecedented; 50 manufacturing firms in 10 European countries contributed to Spacelab, and several different space organizations affiliated with ESA across Europe were involved in the program. The challenge of cohesively managing such a widespread effort was formidable.

NASA and Marshall worked closely with ESA at all levels, and several key members of Marshall's staff worked on-site in Europe to participate in integration and test activities there. In the course of this ambitious effort, new management techniques were devised to control schedules, resources, and costs. The international character of the Spacelab program introduced unusual administrative, fiscal, and technical factors; for example, relatively straightforward matters, such as tracking costs or documenting engineering changes, were complicated by national differences in currency and accounting practices, language and reporting style.

In addition to its program management responsibilities, Marshall was tasked with developing related hardware. As usual, this effort utilized the Center's proficiency in many engineering disciplines. Just as many Saturn facilities and personnel were reassigned to the Shuttle project, many Skylab resources were applied to the Spacelab effort. Marshall people drew upon the Skylab heritage and also developed new solutions for a laboratory compatible with the Space Shuttle. In developing an optical window for scientific observations, for example, they pulled Skylab hardware from inventory and adapted it. On the other hand, development of a pressurized transfer tunnel for the passage of crew and equipment between the Orbiter cabin and the laboratory module was a wholly new effort. Marshall also was responsible for developing experiment software, a vertical access kit for entering the module on the launch pad, and various avionics and environmental control subsystems components. Furthermore, a special Software Development Facility was established to develop and verify programs for the Spacelab experiment computer.

One of the most challenging problems in Spacelab design was the Command and Data Management Subsystem, the centralized control and data collection authority. This three-

computer system is the "bridge" between Orbiter resources and individual experiments. The system also monitors its own health and that of its users, reporting them to the Orbiter and to the payload and mission controllers on the ground. Because the computer system serves two purposes – overall Spacelab subsystem management and experiment operations – imaginative systems and software engineering efforts were necessary. The resultant system is flexible enough to handle diverse experiment requirements within the context of available resources and constraints such as power, attitude, and crew time. During the first mission, this system responded to 16,000 commands and a multitude of timeline changes yet kept Spacelab and experiment operations running smoothly.

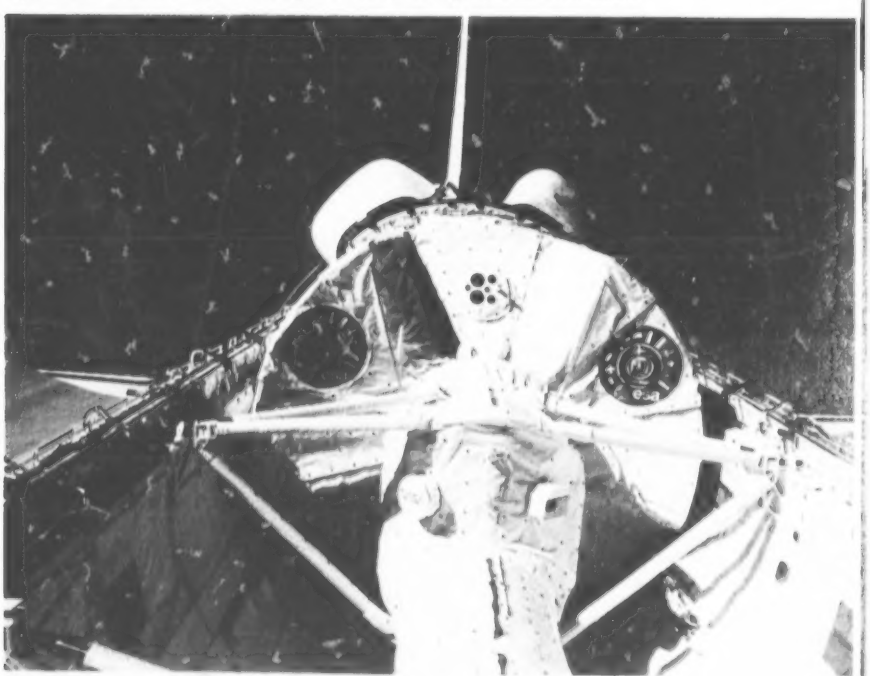
Data transmission also was an engineering challenge that was met with state-of-the-art hardware design. The High Data Rate Multiplexer and High Data Rate Recorder have the most interfaces and most complex operations in the command and data management subsystem. Both can handle data in a range of rates to accommodate widely varying types of instruments in different scientific disciplines. The multiplexer accepts data from experiments, Spacelab systems, and the recorder for transmission to the ground at digital rates up to 50 million bits per second. While running at full speed, the one-inch magnetic tape of the recorder moves at 20 feet per second. During the Spacelab 1 mission, this system was extraordinarily successful; approximately six trillion bits of science data were downlinked.

Spacelab represents a broad cross-section of engineering achievements. Virtually every discipline at Marshall contributed to the design and development of Spacelab. The actual Spacelab systems required the talents of structural, mechanical, dynamic, electrical, hydraulic, metallurgical, chemical, software, and systems engineers. The ground support facilities involved civil, structural, and mechanical engineers, with test and checkout equipment developed by electrical engineers and software professionals. Development of sophisticated scientific instruments required the expertise of electrical, optical, and software specialists. Spacelab demanded the coordinated effort of all these Marshall Center resources.

A PERMANENT PRESENCE

At work in a new laboratory during the Spacelab 1 mission

Spacelab module and tunnel, first used on Spacelab 1 mission



A PERMANENT PRESENCE

Managing Missions

Marshall has a continuing role in the Spacelab program apart from development of the orbital research facility. Through the Spacelab Payload Project Office, the Center plans and directs a variety of missions. Having managed the first three multidisciplinary missions that demonstrated alternate Spacelab configurations, the Center now looks forward to managing several series of flights in particular research fields, such as astronomy, Earth observations, space plasma physics, and materials science. The Center provides the mission manager, mission scientist, integration engineers, and operations personnel for these missions.

The business of Spacelab mission management draws upon many of Marshall's skills in systems engineering and integration at all payload levels from individual instruments to the mated Shuttle-Spacelab. Center personnel plan the layout, perform systems analyses, design and develop integration hardware, oversee assembly and checkout, plan the flight timeline, conduct simulations and training exercises, and provide real-time support during the mission. These activities involve specialists in many different areas, including aeronautical, electronics, software, and human factors engineering. Mission management personnel coordinate all these disparate activities to ensure that the payload meets the scientific goals and uses Shuttle-Spacelab resources most effectively.

Management conference during Spacelab 2 mission

Payload Crew Training Complex, where Spacelab crews prepare for missions

To carry out these complex responsibilities, the Center developed some novel methods and facilities. One of the most successful is the Payload Crew Training Complex (PCTC) in Building 4612, which houses a computerized Spacelab simulator that can be customized for different missions. This facility is a prime training site for Spacelab mission specialists from the astronaut corps and payload specialists from the scientific community. The PCTC is a realistic "classroom" for practicing simultaneous in-flight experiment operations, problem solving, and maintenance procedures. Another achievement was Marshall's effort in outfitting the Operations and Checkout Building at Kennedy Space Center, the integration site for Spacelab payloads. Marshall developed the requirements for the integration facility and its automated test and checkout equipment.

Besides overall mission management, Marshall scientists and engineers are devising experiments for flight opportunities on Spacelab. Apparatus and procedures are being developed here for investigations in all the Center's science disciplines – astrophysics, atmospheric science, solar-terrestrial physics, materials science, and technology. The current level of effort is significant and is expected to remain so in the future.

Spacelab Legacies

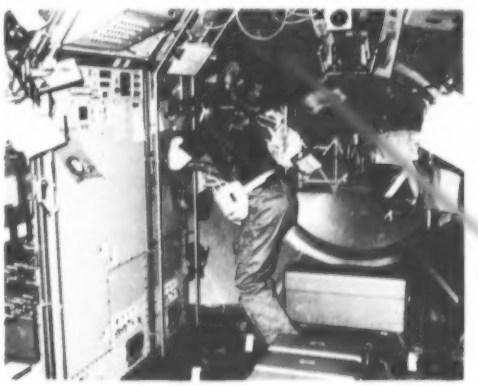
The Spacelab 1 mission, which began on November 28, 1983, was a grand success. With few anomalies, Spacelab performed just as planned and the concept of a system of laboratory modules and pallets for research in space was verified. All the Spacelab subsystems were well exercised by the payload of over 70 investigations in 5 different disciplines. The mission management scheme also was verified; the mission progressed so smoothly and efficiently that an extra day on orbit was

authorized for additional scientific research. The value of onboard payload specialists was confirmed as scientists on the ground communicated frequently and directly with the crew, working together as a team on many experiment operations.

Almost every investigator has reported significant findings from the first Spacelab mission. Materials processing experiments produced much larger crystals with fewer defects than those produced on Earth. Investigations in life sciences challenged reigning theories about subtle physiological reflexes that cannot be tested in normal gravity. Exploratory investigations were carried out to evaluate the potential of Spacelab for astronomical observations and plasma physics research, with very promising results. Other investigations yielded important discoveries about the composition of Earth's atmosphere. Trials of new Earth observation techniques were conducted and showed promise for improved mapping and resource monitoring from space. Spacelab clearly will serve as an important facility for space science research.

Managing a Spacelab mission from the Payload Operations Control Center

Members of the payload operations team on duty during Spacelab missions



Monitoring crystal growth experiments on Spacelab 3 mission

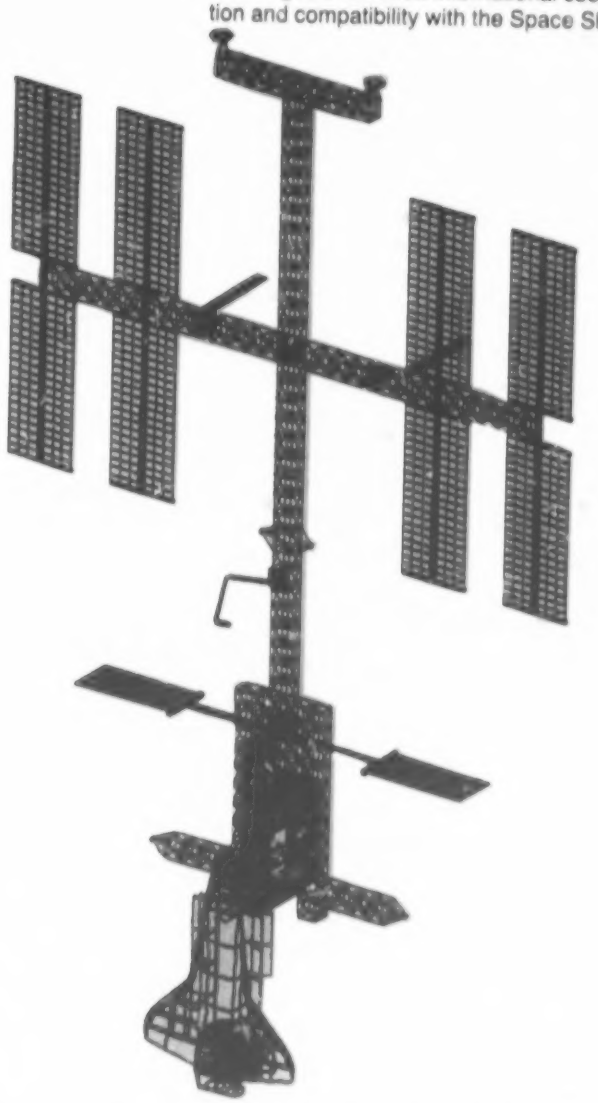
ABOVE: Pioneering research in fluid dynamics during Spacelab 3 mission

LEFT: Payload operations conference during the Spacelab 3 mission

A PERMANENT PRESENCE

The immediate legacy of Spacelab 1 is Spacelab 2 and 3 and a succession of dedicated discipline missions, such as Astro and the Earth Observation Mission, all managed by the Marshall Center. The next accomplishment on the horizon is the opening of a Payload Operations Control Center (POCC) at Marshall for consolidated local operations during Spacelab missions. In the past, Marshall personnel have participated in real-time mission activities from two locations, a POCC in Houston and the Huntsville Operations Support Center (HOSC). The new POCC in Huntsville will supplement the one at the Johnson Space Center for missions managed by Marshall.

By virtue of its Skylab experience, Marshall Space Flight Center had a head start on Spacelab. Yet, Spacelab introduced the new challenges of detailed international cooperation and compatibility with the Space Shuttle.



This effort was complicated by the fact that Spacelab development occurred in parallel with Orbiter, payload, communications satellite, and ground support development. Changes in any one element had an impact on the others. Spacelab management personnel and their engineering teams met the exceptional challenge of keeping Spacelab development synchronized with the other efforts and responding to changes as they arose. Marshall again proved its ability to manage development of a large, complex manned system. The Center also expanded its role to include extensive crew training responsibilities, using the time-honored techniques of simulation and step-by-step preparation.

Beyond the series of Spacelab missions, another legacy is evolving. When the President announced the Space Station initiative, he referred specifically to the engineering and scientific achievement of the Spacelab 1 mission just a month earlier. The largest manned system ever attempted is the Space Station; architectural concepts for the new facility include Spacelab-type modules and pallets.

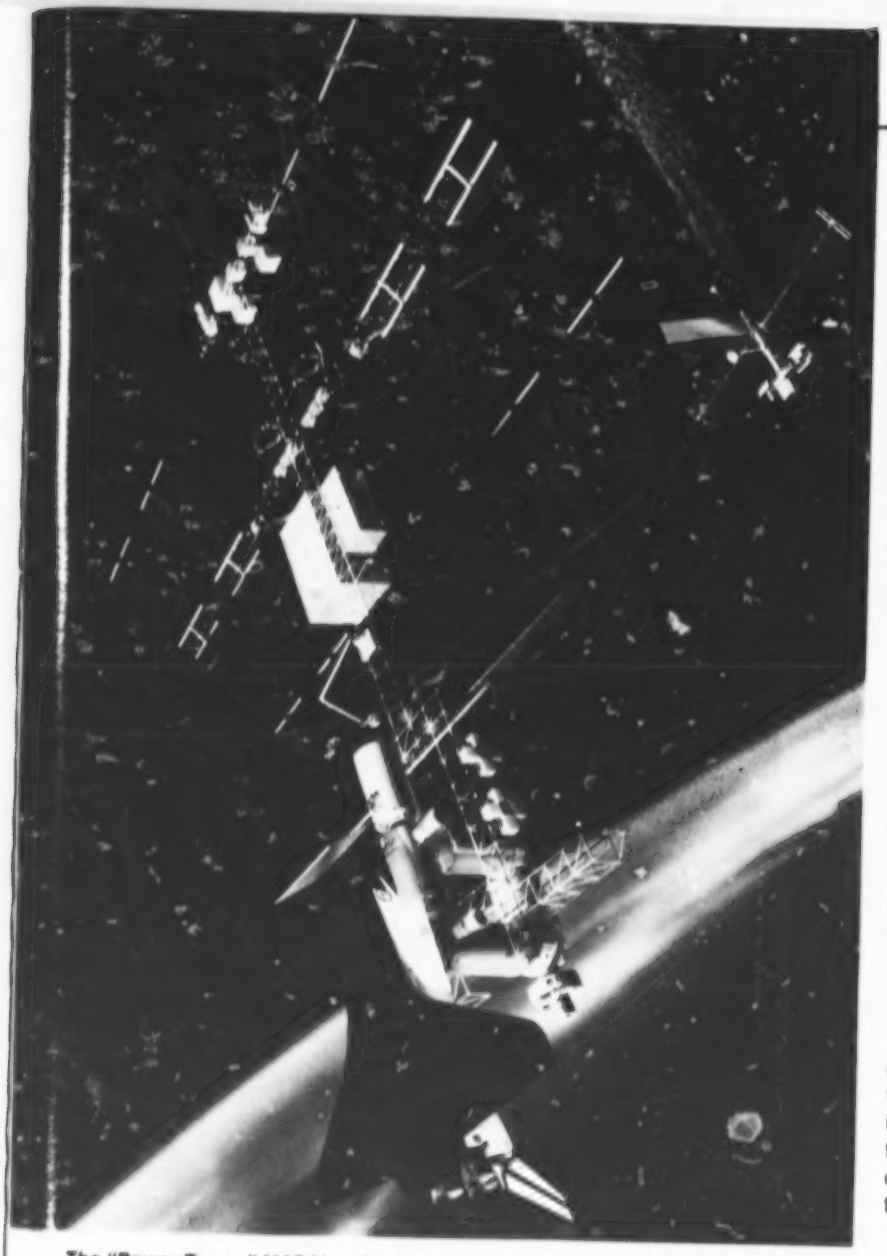
The Space Station does not displace the Shuttle and Spacelab; rather, it extends their capabilities. The three programs are complementary, and Marshall expects them to be parts of an integral system continually incorporating new ideas and technology advances.

The Spacelab work done at Marshall yesterday and today is directly applicable to tomorrow's major project, the Space Station. The Center has sound credentials for developing and managing large manned systems for space science and applications. Both the hardware and the functions of the proposed Space Station owe a debt to Spacelab which Marshall is uniquely prepared to redeem. As in the past, the Center is encouraging its resident experts to meet the challenges of the future.

Space Station

The Marshall Center's three major lines of commitment converge at the Space Station. This ambitious project represents a synthesis of the Center's principal interests in vehicles, science payloads, and manned space systems. As it moves into the Space Station era, Marshall Space Flight Center expects to use its various legacies for bold new ventures.

In 1984, after years of preliminary conceptual groundwork, NASA organized a full-fledged Space Station definition effort. Responsibilities for various Station elements



The "Power Tower," NASA's reference configuration for Space Station planning

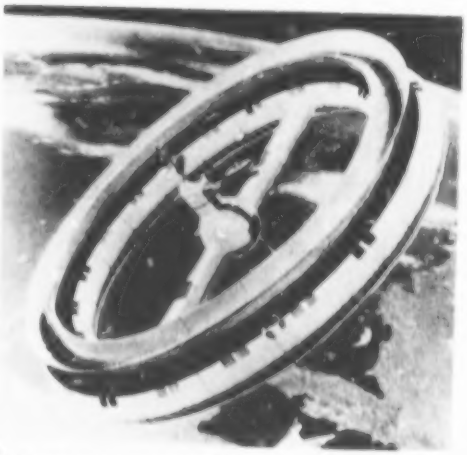
were delegated to different centers, and Marshall received a major portion of the work: definition and preliminary design of pressurized common modules for use as laboratories, living areas, and logistic transport; environmental control, life support systems, and propulsive systems; a module equipped as a laboratory and others as logistics modules; and accommodations for auxiliary Orbital Maneuvering Vehicles and Orbital Transfer Vehicles.

The Space Station reference configuration selected as a beginning point for design studies is called a "Power Tower." It consists of a tower of beams, solar panels, antennas, co-orbiting platforms, and enclosed modules; altogether the Space Station is about 400 feet in length, somewhat longer than a football field. Most of the technology for the Station's initial structure and systems is presently available. However, the Space Station presents a host of new engineering challenges as Marshall, once again, seeks to do something that has never been attempted.

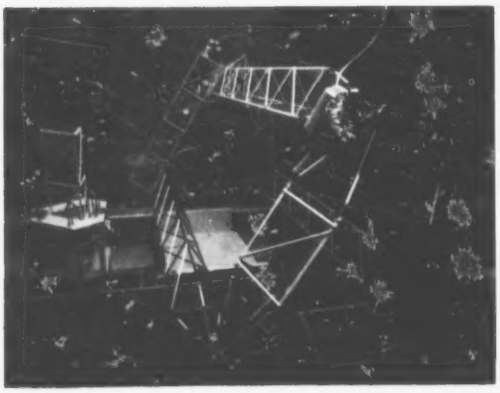
Because the Space Station is intended to be permanent, it must be designed for maintenance, repair, and refurbishment. All maintenance and reconfiguration will occur in space and will be accomplished by astronauts or automated devices under the extraordinary working conditions of weightlessness, vacuum, and 90-minute cycles of daylight and darkness. The design requirements for long-term maintainability demand advances in long-life materials, automated "expert systems" for inspection and repair and remote operations, sophisticated contamination control measures, crew mobility systems and

"Tonight, I am directing NASA to develop a permanently manned space station and to do it within a decade."

President Ronald Reagan
January 25, 1984



A space station envisioned years ago by Dr. von Braun



Assembling large space structures underwater at MSFC

tools, and new orbital repair techniques. Although some spacecraft are now being designed for repair or refurbishment in orbit, there is no precedent for orbital servicing on the scale of a Space Station. Astronauts have never yet welded in space, for example, nor have they had to seal punctures on a spacecraft damaged by micrometeoroids. Space Station designers must plan for a variety of contingencies that were not factors in smaller, short-lived, or returnable spacecraft.

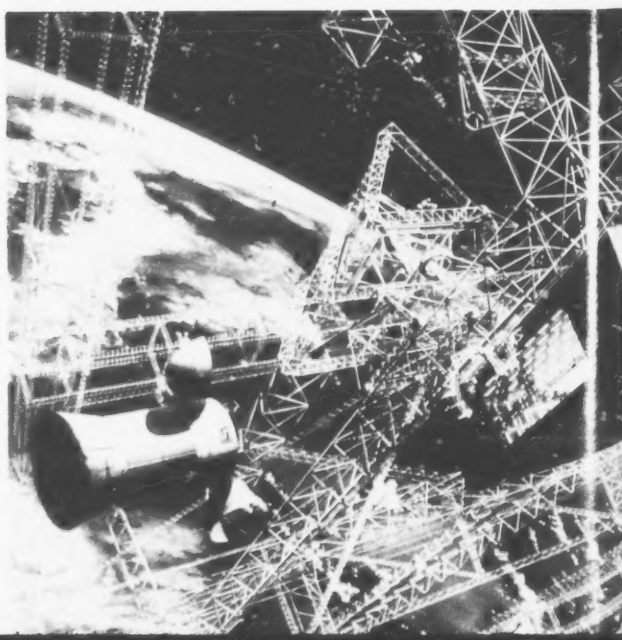
The Space Station also must be designed for expansion as new technologies become available and as needs change. The initial configuration is a nucleus for an enlarged future Space Station having more elements. In addition to major structural changes, the

Evaluating techniques for construction projects in space

"History will remember you as the pioneers, the bold ones who stepped out into this new frontier and made possible these great new dreams and new benefits that mankind is only just beginning to realize."
Dr. Eberhard Rees, 1970

Marshall's underwater model of the Manned Maneuvering Unit, which extends range of astronauts working in space

Concept for a space operations center with elements similar to those evaluated at Marshall



A PERMANENT PRESENCE

Space Station will change payloads as science and technology evolve; an entire observatory or laboratory may be replaced, or individual instruments may be exchanged for newer models. Evolutionary growth means frequent integration and deintegration of mission equipment. These activities are normally performed under stringent environmental and quality control conditions on the ground; designing and planning for these operations in space is another challenge.

Apart from these formidable design problems, the actual construction of the Space Station is a major challenge in systems engineering and logistics. Delivering all the parts into orbit and assembling them properly will be quite a feat. The Space Station is a complex configuration of large beams, towers, platforms, modules, and solar arrays. Containing all the cables, wiring, pipes and ductwork for its utilities services, the Space Station requires advances in systems that provide electrical power, fluid storage and distribution, environmental control, and life support. Advances in assembly techniques are also required to guarantee that all parts connect properly and function well.

Marshall has already addressed many of the conceptual and practical problems associated with building large structures in space. Since the mid-seventies, several feasibility and definition studies have focused on space platforms and power systems. Concurrently, alternative assembly and deployment techniques have been evaluated in the Neutral Buoyancy Simulator and NASA's KC-135 airplane, and demonstrations are planned for upcoming Shuttle flights. For some such studies, Marshall has used a prototype beam fabrication machine.

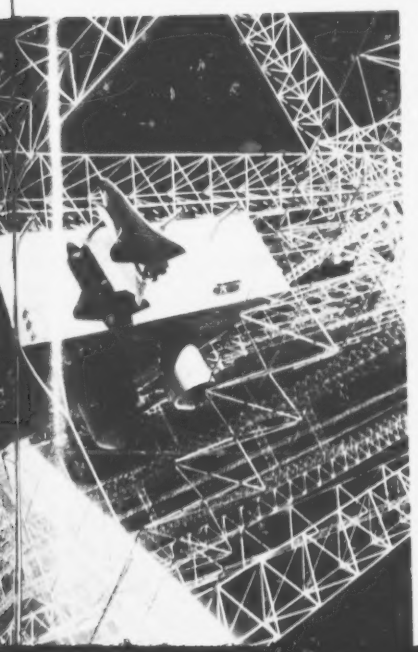
The Center has also assessed the roles of humans and automated systems in space. To be economical and efficient, the Station must operate without a large contingent of maintenance workers and service personnel. Planners are looking ahead to determine what tasks and functions can be handled by automation and robots.

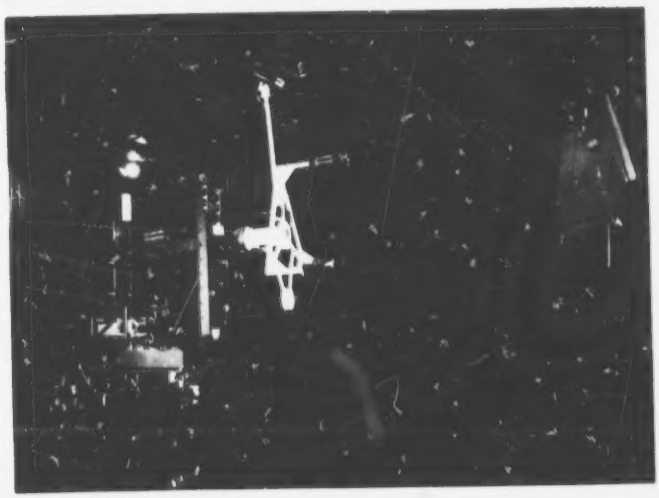
To meet the challenges of Space Station architecture, utilities services, and auxiliary vehicles, the Center will rely on its resources in many engineering disciplines. New technology is required to improve the efficiency of virtually every subsystem. The Marshall Center is already involved in advanced technology for environmental control, attitude control, thermal control, propulsion, and long-life materials. Experts in structures, materials, dynamics, fluids, electronics, software, crew systems, and other areas of systems engineering are prepared and eager to join this new adventure in the utilization of space as a work place.

Related work is also under way to evaluate complementary systems that would enhance a Space Station; large space structures, orbital transfer vehicles, and robotics and teleoperators are typical examples of advanced planning concepts. Thus, Marshall is involved in comprehensive planning for a broad base of operations in space.

The eventual extent of the Center's sphere of influence on the Space Station depends on the evolution of the Space Station itself. Many roles or functions are possible. The Center has anticipated them and has become sufficiently diverse in its mix of capabilities to

Operator controlling a spacecraft rendezvous and docking simulation from remote control room





Docking simulation in Marshall's teleoperation and robotics research laboratory

assume any of the Space Station responsibilities with high confidence of success.

Initially, the Space Station will be used as a service center for orbital craft and scientific payloads. Marshall already has a major role developing the accommodations for orbital servicing, and the Center may become responsible for outfitting the necessary workshops and hangars. The Center is well qualified to develop both manual and automated techniques for orbital maintenance and repair services as well as tools and crew systems. Some of the pioneering work at Marshall in the next few years will be in the development of accommodations and techniques for a service station in space.

The initial Space Station also will serve as an observatory platform for astronomy, solar science, and Earth observations. Marshall may provide new generations of research instruments for use there. The Center is well versed in the design and operation of space telescopes in all sizes and wavelength ranges. Besides astronomy instruments, the Center also has experience in the tools for Earth observations and space plasma physics investigations.

Later, when the Space Station becomes a transportation node or launch site for space vehicles, Marshall may provide craft not only for nearby operations (the space "tugs") but also for lunar and planetary expeditions. Such far-ranging missions may be either manned or unmanned. As the Space Station becomes a large orbital base of operations for a fleet of vehicles, Marshall will once again play a major role in missions to the moon and beyond. The Center undoubtedly will become heavily involved in the exploration of space beyond low-Earth orbit.

When the Station becomes a logistics base to support large-scale construction projects in space or mining on the moon, Marshall may well provide the necessary technology. An intriguing idea now under study is propellant scavenging from discarded fuel tanks and surplus reservoirs on board orbital craft. Marshall may develop technology for siphoning operations and fuel depots in space. Planning and eventually managing the assembly of large space structures and the integration and checkout of their payloads will be major activities at the Marshall Center.

When the Space Station or nearby platforms develop into manufacturing sites for space-processed materials, Marshall's role in the commercial use of space will grow dramatically. Already the Center sponsors extensive research in microgravity materials processing for both commercial and scientific missions. Some participants speculate that materials science has the same potential for commercial development in space as that already achieved by the communications industry. Marshall is prepared to cooperate with private industry as a partner in this endeavor.

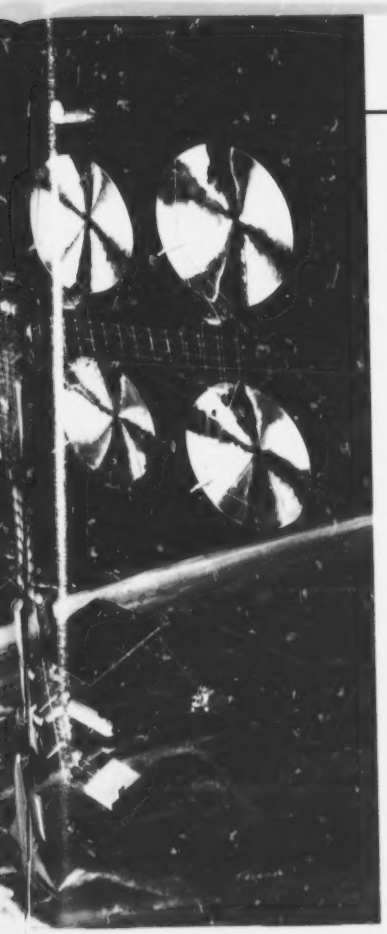
A relatively recent consideration in Space Station planning is the use of tethers, long cables attached to the Station. Already under development at Marshall, these tethers can serve a variety of purposes: as "leashes" to keep co-orbiting spacecraft from drifting too far away, as lines to "reel in" freeflying craft for servicing, as "elevators" to transfer supplies between higher and lower craft without actual docking, or as power lines in an electrical power generating system. The list of potential tether applications is growing, and the Center expects to do some exciting work with tethers in the near future.

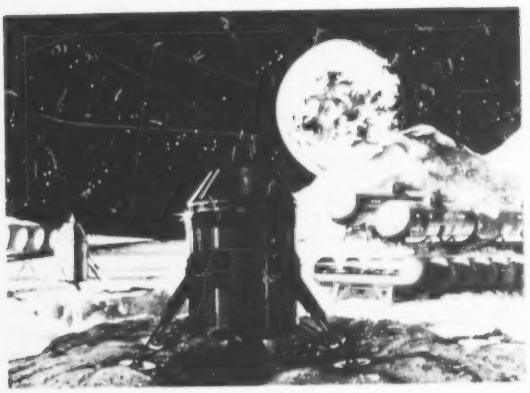
In short, Space Station activities will influence the growth of the Center for the next quarter century. Marshall anticipates a greatly expanded role in orbital assembly and servicing activities and in lunar and deep space exploration. Having already introduced joint endeavor agreements for commercial ventures in space, Marshall expects to develop new kinds of business partnerships in the Space Station era. Marshall also will be taking advantage of the opportunity to do continuous scientific research on orbit 24 hours a day, 365 days a year. The Center has proven capabilities in all the relevant disciplines of science, engineering, and management to evolve with the Space Station.

With the Center's strong legacies to their credit, Marshall's experts today are in an enviable position. They are the ones who will realize the dream of the early rocket pioneers – a permanent presence in space. ■

Vision of the future: concept for the Space Station

Concept for a commerc materials processing facil near the Space Stati



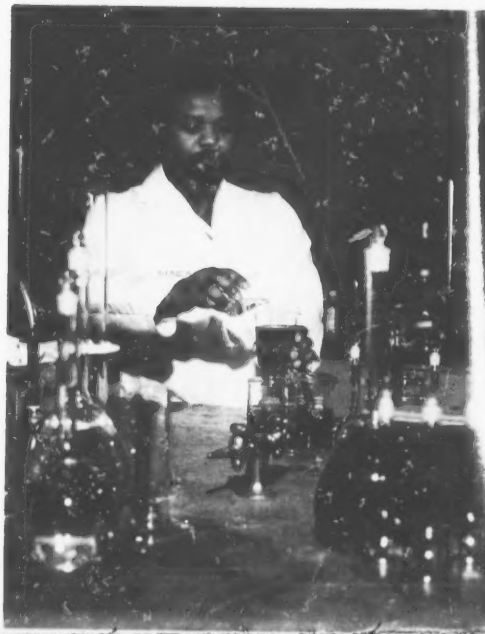


Concept for a mining base on the moon

"We can follow our dreams to distant stars, living and working in space for peaceful, economic, and scientific gain."
President Ronald Reagan

FOUNDATION FOR THE FU

THE MARSHALL CENTER PEOPLE



TURE:

Credit for the successes of Marshall Space Flight Center during its first quarter century belongs to the employees. References to the multidisciplinary capabilities of this Center are really references to people – to engineers, scientists, managers, procurement and finance specialists, secretaries, computer and communications technicians, illustrators, attorneys and personnel specialists, machinists, welders, and workers in a host of other occupations throughout the laboratories, shops, and offices. Over the years, four directors have guided the Center through a carefully planned diversification from one dominant program in the early Saturn years to the broad variety of programs today.

Dr. Wernher von Braun, from 1960 to 1970, brought Marshall Space Flight Center into existence and directed the tremendous Saturn

"Marshall's people are its strongest assets. . . people with a sense of the importance of the work they are doing and pride in their accomplishments."
Dr. W. R. Lucas

Dr. Wernher von Braun
Director, 1960-1970

Dr. Eberhard Rees
Director, 1970-1973

Dr. Rocco A. Petrone
Director, 1973-1974

Dr. William R. Lucas
Director since 1974

endeavor with energy and foresight. Dr. von Braun's challenge, indeed NASA's challenge, was to form an organization of the best talent to invent and prove the technology for launch vehicles capable of sending Americans to the moon. That no one knew exactly where the moon was or precisely how to get there was no deterrent. The technological effort of the Saturn years is without parallel in our history. Never before nor since have so many people in government, industry, and universities been orchestrated to work together on a project of such complexity and originality as the manned lunar landing.

As the Saturn launch vehicles became reality, Marshall's leadership envisioned other roles for the Center. With foresight and prudence, the Center embarked on a carefully planned, deliberate course of diversification into the development of scientific payloads, manned systems, and other vehicles for further exploration and utilization of space. The first Director of the Program Development office, established in 1969 to guide Marshall's evolution toward new responsibilities, was Dr. W. R. Lucas. During his tenure in this position, the Center began a concentrated effort to broaden the scope of its missions and conceive new post-Apollo programs for the space agency.

Meanwhile, Dr. Eberhard Rees served as Center Director from 1970 to 1973 during a period of transition. Under his leadership, the Saturn-Apollo program was completed, the Skylab program was implemented, and formulation of the Shuttle concept began. During the tenure of Dr. Rees, the agency, and the Marshall Center in particular, experienced fiscal and manpower reductions that presented new managerial challenges. Although many valued employees were lost, the Center retained its capabilities in all disciplines and emerged from this period with renewed energy.

For the next year, Dr. Rocco Petrone served as Marshall's Director and presided over the extraordinary Skylab program. In three successful missions, including the dramatic rescue operations, Marshall demonstrated convincing expertise in scientific payloads and manned systems. The Center reapplied experience gained in the development of launch vehicles to this ambitious systems engineering project and succeeded admirably. During this period, the Center's organization was restructured to accommodate Marshall's changing roles and responsibilities. The result has been a streamlined, more efficient institution, ambitious and undaunted.

In 1974, Dr. W. R. Lucas began his term as Center Director, a position he holds today and has held longer than any other Marshall Center Director. Marshall bears the stamp of his influence. As Dr. Lucas advanced through key positions at all levels from the laboratory onward, he has insisted on the virtues of competence, discipline, and the commitment to excellence. Under his leadership, the Center has become diversified and has remained one of the foremost technical and managerial elements of NASA. It has been speculated that the systems engineering capabilities of the Marshall Center could be applied to any large-scale technological challenge – a national transportation system, for example, or energy systems – and Marshall could handle the problem just as successfully as it has met its space program challenges. This multidisciplinary expertise is rare and valuable.

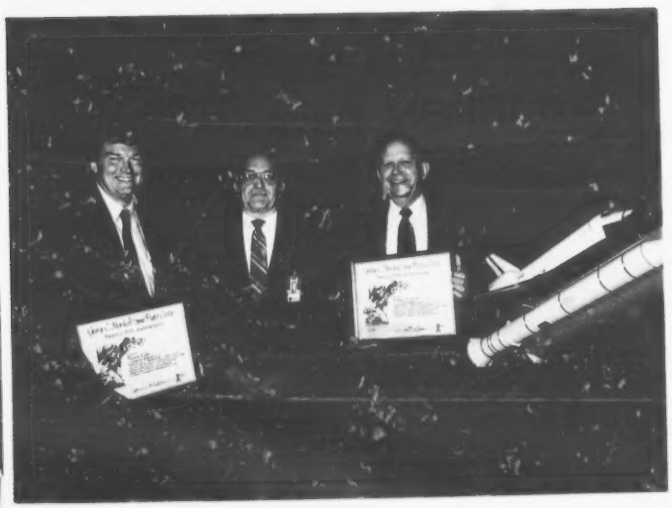
With the leadership of these four directors, Marshall Space Flight Center has established a reputation for technical competence. The Center has had major responsibilities for many of NASA's key programs in launch vehicle development, scientific spacecraft, orbital laboratories, and pioneering research. While

"Although we look with pride on our achievements of the past. . . we recognize that we must prove ourselves each year."
Dr. W. R. Lucas

these past achievements are a source of pride, their real importance today is that they are the foundation for the Center's future. In these accomplishments, Marshall has developed the ability and experience to meet the new challenges of the Space Station era.

Exciting opportunities for achievement await the next generation of Marshall leadership and employees. Establishment of a permanent presence in space on a manned space station, ventures into deeper space, perhaps a return to the moon or manned excursions to the planets, development of new space vehicles, commercial enterprise in space, sophisticated orbital laboratories and observatories all demand ingenuity, skills, and talent on a scale comparable to that of the past.

Scenes from the Marshall Center's 25th Anniversary



FOUNDATION FOR THE FUTURE

The challenges of the future require experienced managers, engineers, and scientists and also the abilities of highly motivated young professionals. The Marshall Center today is in an excellent posture to meet the future. The current work force is a blend of mature employees and new recruits. Many of the experienced employees have worked on several major projects and have risen to leadership positions, applying their competence from one program to the next. This continuity of skill and experience is enhanced by the infusion of new talent; entry level employees, fresh out of educational and training programs, add new knowledge and capabilities to Marshall's inventory.

Engineers and scientists make up almost two-thirds of the Marshall Center work force today, with a wide variety of business professionals, clerical personnel, and technicians making up the other third. More than two-thirds of the employees have college degrees, and many have earned graduate degrees. The Center has proficiency in all the relevant engineering disciplines for complex space systems, and its cells of science are advancing the frontiers of space research. The work force skills are sufficient and well balanced to meet the challenges of the present and foreseeable future. Expertise in many fields invigorates this Center and keeps it strong and supple.

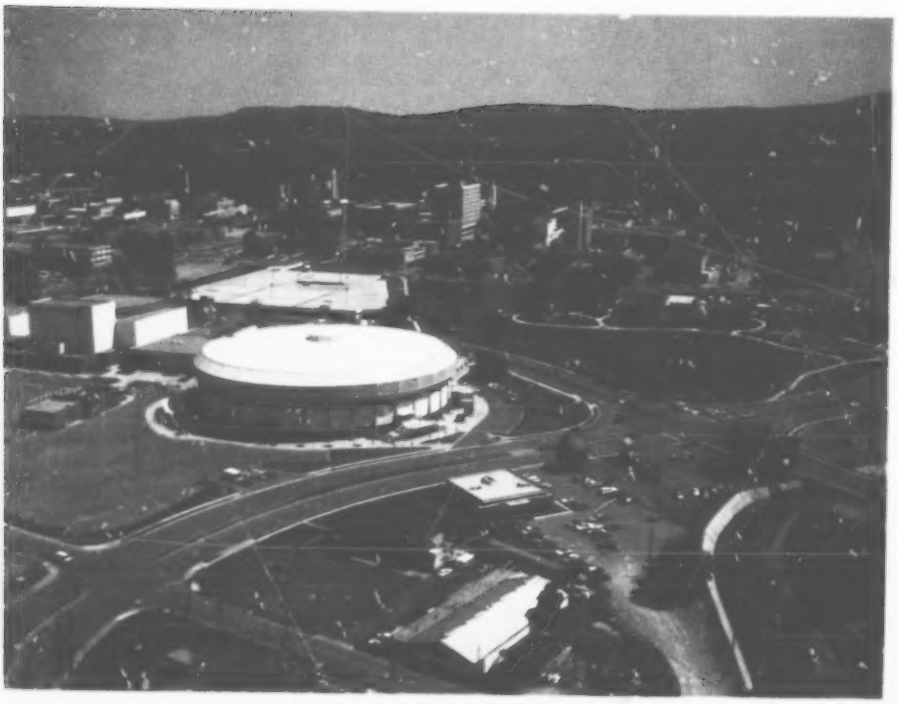
The Marshall Center is a highly disciplined organization noted for its technical excellence and meticulous attention to detail. Its bold achievements result from careful planning and methodical progress by people who are dedicated to the common goal of excellence. As Marshall people meet the challenges of the nation's space program, usually pushing the state of the art within tight schedule and funding constraints, they insist on "doing things right" and "making it work." The personnel here are confident, creative, and well prepared to tackle any problem; if the appropriate materials or methods do not exist, Marshall people will develop them.

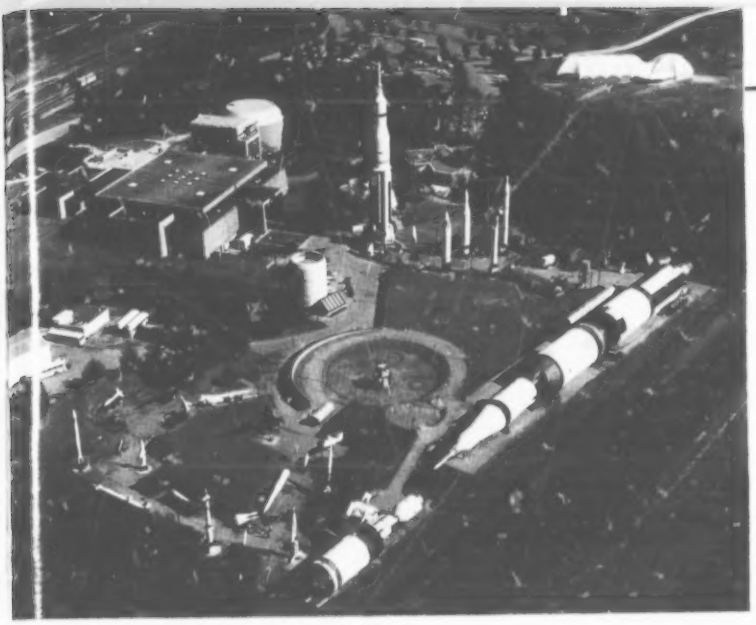
The disciplined work ethic here arises in part from the Center's proven management philosophy and also from the individual's sense of responsibility. People are aware of the historic importance of their work and are challenged daily to be perfectionists, to give their best effort. This commitment to excellence fosters personal satisfaction and is the basis for the Center's many successes.

These attitudes and values enrich the broader community as well as the Center. Marshall's people are active in civic affairs in Huntsville and the surrounding areas, giving generously of their time and talents to enhance the quality of life here. They bring to a multitude of community projects the same devotion and energy that characterize their NASA work. The annual Combined Federal Campaign of charitable fund-raising is but one impressive example of employees' contributions to the community; the roster of contributors and volunteers to virtually every civic organization includes Marshall employees.

The Center is fortunately situated in a supportive community, where it enjoys a friendly relationship with its neighbors, the United States Army on Redstone Arsenal and the universities in Huntsville. The mutually beneficial community ties that originated in the 1950's are sustained at the institutional and individual levels by people whose dedication reaches beyond the work place.

The people of Marshall Space Flight Center are its strongest asset, as important to the present and future space program as the rocketry pioneers were to the past. Like the early von Braun rocket team, they are a unique national resource. ■





Alabama Space and Rocket Center Archives photo

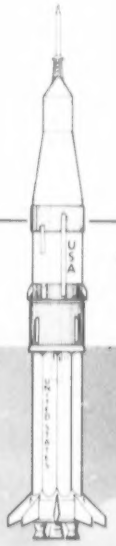
"Our community has been and continues to be vitally important to the success of America's space program."
Dr. W. R. Lucas

Community ties

CHRONOLOGY 1960-1

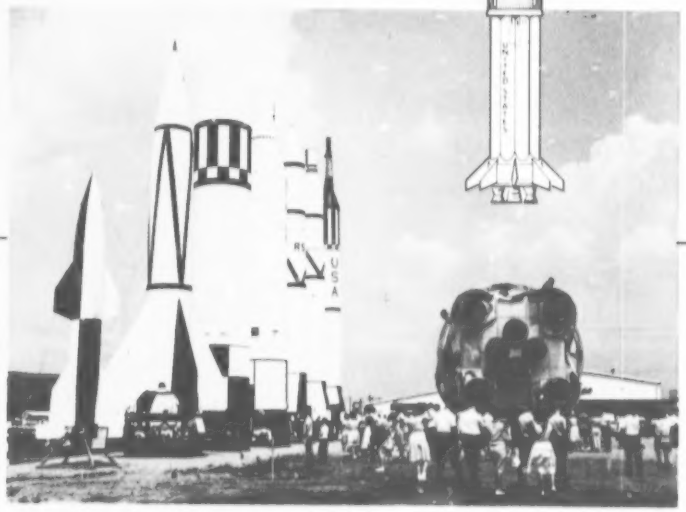
VEHICLES

- Explorer I (Jupiter C) launched America's first satellite (1958)
- Saturn development authorized (1958)
- Saturn program given highest national priority rating
- 1st Mercury-Redstone launch with live payload (chimpanzee)
- 1st manned Mercury-Redstone launch and suborbital flight
- 1st Saturn I launch
- 2 Saturn I launches
- 1 Saturn I launch
- 3 Saturn I launches
- 3 Saturn I launches, last in series of 10



SPACE SCIENCE AND TECHNOLOGY

- Explorer I: discovery of Van Allen radiation belts (1958)
- Project Highwater completed
- 3 Pegasus micrometeoroid detection satellites launched



MANNED SYSTEMS

THE CENTER

- Static Test Tower (Bldg. 4572) completed (1957)
- NASA established by National Aeronautics and Space Act (1958)
- Project Mercury authorized (1958)
- Project Mercury astronauts selected (1959)
- MSFC established; Dr. Wernher von Braun named 1st Director
- President Eisenhower dedicated MSFC
- President Kennedy set goal of manned lunar landing by end of decade
- Michoud Operations production facility added
- Construction of Saturn launch facilities in Florida under MSFC direction
- President Kennedy visited MSFC
- Slidell Computer Facility acquired
- MSFC Launch Operations Directorate became separate NASA Center in Florida
- Central Laboratory and Office Building (4200) completed
- Propulsion Test Facility (F-1 Engined Test Stand Bldg. 4696) completed
- Mississippi Test Operations added (later renamed Mississippi Test Facility)
- Major MSFC reorganization established two directorates
- Barge docks and Saturn Road built
- Saturn V Dynamic Test Facility (Bldg. 4550) completed
- Propulsion Systems Components Test Facility (F-1 Turbopump Test Facility) (4548) complete
- Engine Component Test Facility (Test Complex 300) completed
- Model Propulsion Systems Test Complex (Bldg. 4540) completed
- Target Motion Simulator activated in Bldg. 4663
- Vehicle Components Hangar (4755) complete
- Thermal Vacuum Chamber (Bldg. 4557) installed
- Machine Shop and Assembly Shop (Bldg. 4550) completed
- Propulsion System Test Stand (S-IVB Test Stand for J-2 Engines, Bldg. 4514) and cryogenic storage facilities completed
- HOSC established in Bldg. 4663
- Load Test Annex (Bldg. 4619) constructed

THE COMMUNITY

- Huntsville population 16,000 (1950)
- German rocket group moved to Huntsville (1950)
- Huntsville Symphony organized (1955)
- Huntsville population 72,000
- J.F. Drake State Technical College opened
- Research Institute founded
- Huntsville Arts Council organized
- Cummings Research Park established
- U.S. Army MICOM established
- UAH Foundation established
- New Chamber of Commerce and municipal buildings completed
- Jetplex Industrial Park established

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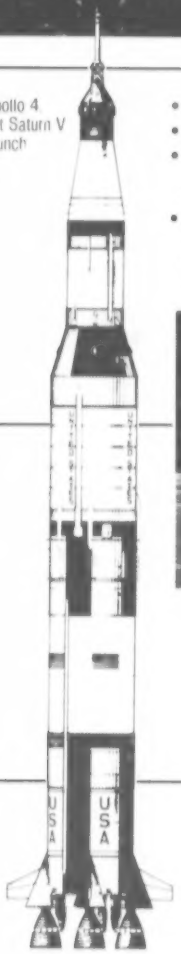
- 3 Saturn IB launches

- Apollo 4 1st Saturn V launch



- Apollo 5 (Saturn IB)
- Apollo 6 (Saturn V)
- Apollo 7 (Saturn IB) 1st manned Apollo mission
- Apollo 8 (Saturn V) 1st manned lunar orbit mission

- Apollo 9 (Saturn V)
- Apollo 10 (Saturn V)
- Apollo 11 (Saturn V) men land on moon
- Apollo 12 (Saturn V) 2nd manned lunar landing
- Space Shuttle Phase A studies completed

- Apollo 13 (Saturn V)

- Apollo 14 (Saturn V) 3rd manned lunar landing
- Apollo 15 (Saturn V) 4th manned lunar landing
- MSFC Space Shuttle assignments announced

- Apollo 1
- Apollo
- Space

- Skylab Apollo Telescope Mount project began

- 1st microgravity materials processing demonstrations and experiments

- Space
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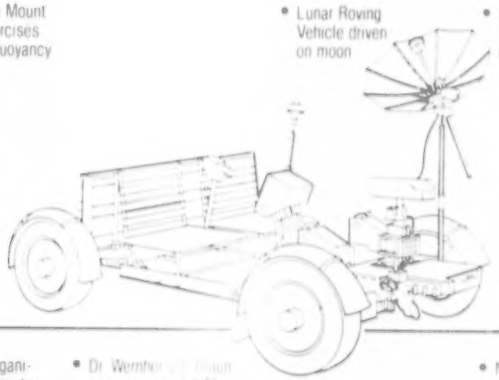
- Apollo Telescope Mount (Skylab) EVA exercises held in Neutral Buoyancy Simulator (NBS)

- Lunar Roving Vehicle driven on moon



- Lunar R
- Vehicle
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- Propulsion System Component Test Stand; Test Complex 500 (Bldg. 4522) and related facilities completed
- Welding Shop; Electrical Shop (Bldg. 4705) completed
- Saturn/Apollo Applications Office established

- S-II Structural Test Facility (Bldg. 4699) completed
- Neutral Buoyancy Space Simulator (Bldg. 4705) completed

- Major MSFC reorganization; four directorates established
- Six-Degree-of-Freedom Motion System activated in Bldg. 4663
- Solar Magnetograph Facility (Bldg. 4347) completed
- Space Shuttle Task Team established

- Dr. Wernher
- reassigned
- Headquarters
- Dr. Eberhard Rees
- Center Director

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- Lowe Industrial Park established
- Madison County Industrial Park established
- New Huntsville-Madison County Public Library opened

- Huntsville-Madison County Jetplex opened
- New Madison County Courthouse completed

- U.S. Army Advanced BMD Agency formed

- University of Alabama in Huntsville (UAH) established
- Huntsville Association of Technical Societies formed
- Grissom, White, Chaffee public schools dedicated

- Huntsville population 139,000
- Alabama Space & Rocket Center opened
- Huntsville Museum of Art founded

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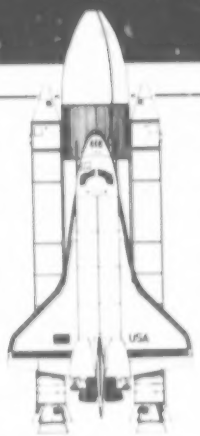
- Apollo 16 (Saturn V): 5th manned lunar landing
- Apollo 17 (Saturn V): 6th manned lunar landing
- Space Shuttle configuration announced

- Final (13th) Saturn V launch (Skylab)
- 3 Saturn IB launches (Skylab Crews)

- Final (9th) Saturn IB launch (Apollo-Soyuz Test Project)
- 1st test firing of Space Shuttle Main Engine (SSME)



- 1st Solid Rocket Motor test fired (in Utah)
- 1st External Tank tests began at MSFC

- Shuttle Orbiter "Enterprise" arrived for Mated Vertical Ground Vibration Tests
- 1st assembly of complete Space Shuttle
- Main Propulsion Test series (SSME cluster firings) began at NSTL (Mississippi)

- Mated Ver... Vibration T... completed
- Shuttle sc... acoustic t...
- External T... tance test... checkout
- Solid Rock... developme... completed... firings sta...

- Space Telescope assigned to MSFC

- 3 multidisciplinary Skylab missions with Apollo Telescope Mount solar observatory. MSFC investigations in materials processing and solar physics
- Space Telescope definition and preliminary design activities began

- Saturn V test stand used as drop tower for microgravity materials processing experiments
- Final Skylab mission (84 days) completed*

- 1st in series of 10 SPAR flights of materials processing experiments

- Lageos and Gravitational Probe A launched
- 2 SPAR flights

- HEAO-1 launched; discoveries reported
- HEAO-2 telescope tested in new X-Ray Calibration Facility
- Spacelab 1 and 2 investigators selected; first meetings held
- Space Telescope investigators selected
- SPAR flight
- Spacelab simulation (ASSESS) held

- HEAO-2 launched; sent 1st X-ray image of star
- AXAF conceptual design study completed
- SPAR flight
- MSFC studied large space platforms

- HEAO-2 ... reported
- HEAO-3 ...
- Skylab re... atmosphe... integrated
- Spacelab ... investigat...
- MSFC as... ment res... OSTA-2 ... payload ... Experime...
- SPAR fli...

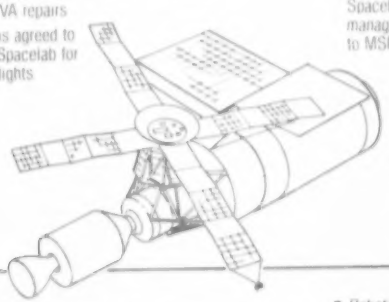
- Lunar Roving Vehicle used on 2 missions

- Skylab launched; 3 manned Skylab missions
- Many NBS tests for Skylab EVA repairs
- Europeans agreed to develop Spacelab for Shuttle flights

- Record 84-day Skylab manned mission completed

- Apollo-Soyuz Test Project
- Spacelab 1 and Spacelab 2 project management assigned to MSFC

- Spacelab 3 project management assigned to MSFC



- Skylab reactivated for possible reuse, reboost or deboost; project discontinued within the year
- Spacelab 1 and Spacelab 2 payload specialists selected; crew training began

- Full-scal... bay insta...
- Tests of ... Telescop... procedur... techniqu... space st... in NBS

- Major MSFC reorganization
- Program offices established for Skylab and HEAO
- Shuttle Projects Office established
- President Nixon announced decision to develop Shuttle

- Dr. Eberhard Rees retired
- Dr. Rocco A. Petrone became Center Director
- Spacelab Program Office established
- Michoud Assembly Facility modified for production of Shuttle External Tanks

- Dr. Petrone reassigned to NASA Headquarters
- Dr. William R. Lucas became Center Director
- Science & Engineering Directorate reorganized
- Mississippi Test Facility became independent NASA installation (National Space Technology Laboratories)

- Robotic & Teleoperator System Evaluation Facility activated in Bldg. 4705
- Conversion of Saturn facilities for Shuttle testing initiated

- Spacelab Payload Project Office established
- Special Projects Office established
- Saturn Program Office phased out
- X-Ray Calibration & Test Facility completed in Bldg. 4708
- Solar Heating & Cooling Test Facility opened

- Space Telescope Project Office established
- Saturn IB Static Test Stand (Bldg. 4572) modified for Solid Rocket Booster testing
- Saturn IC Dynamic Test Facility (Bldg. 4550) modified for Shuttle testing

- Materials Processing in Space Projects Office established
- Space Shuttle unloading facility prepared at Redstone Arsenal
- Shuttle route modified from Airfield to test areas
- HOSC reactivated for Shuttle launch support

- Construction began on Memorial Parkway overpass system

- UAH School of Primary Medical Care established

- U.S. Army BMDSCOM and BMDATC established

- Alabama A&M Centennial
- Von Braun Civic Center completed

- First phase of Memorial Parkway overpass system completed

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MARSHALL SPACE FLIGHT CENTER

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- SSME acceptance tests
- 1st Space Shuttle assembled at Kennedy Space Center

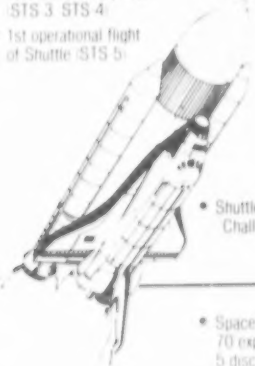
- 1st Space Shuttle mission (STS-1); Orbiter Columbia introduced
- 2nd Shuttle mission (STS-2)

- Shuttle Orbital Flight Test series completed (STS-3, STS-4)
- 1st operational flight of Shuttle (STS-5)

- 4 Shuttle missions (STS-6 through STS-9)

- 5 Shuttle missions
- Shuttle Orbiter Discovery introduced

- 10 Shuttle missions scheduled
- Shuttle Orbiter Atlantis introduced



- Shuttle Orbiter Challenger introduced

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- 2 SPAR flights
- 1st Joint Endeavor Agreement (MSFC and McDonnell Douglas) for materials processing in space

- SPAR flight
- Space Telescope mirror polishing completed

- Spacelab 1 mission; 70 experiments in 5 disciplines; mission scientist, some principal investigators and co-investigators from MSFC
- 10th and final SPAR flight

- Solar Array Flight Experiment (OAST-1) mission; demonstration of advanced solar array technology
- Space Telescope's Optical Telescope Assembly completed and delivered

- Spacelab 2 mission; 13 investigations in 7 disciplines
- Spacelab 3 mission; 15 investigations in 5 disciplines
- Space Telescope assembly in progress

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lled in NBS
Space
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uctures held

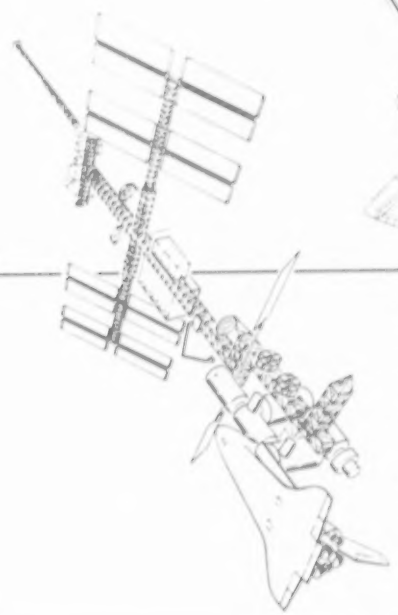
- ESA delivered major Spacelab components
- Spacelab integration began

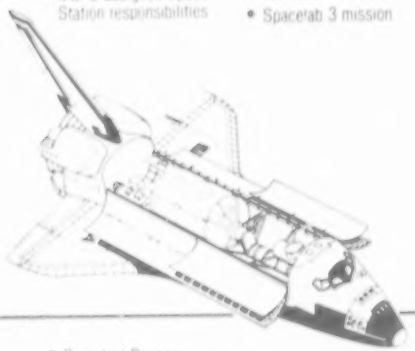
- Spacelab 3 payload specialists selected

- 1st flight of Spacelab (10 days)

- MSFC assigned Space Station responsibilities

- Spacelab 2 mission
- Spacelab 3 mission





- Spacelab Payload Crew Training Complex activated in Bldg. 4612

- Integrated Software Development Facility & Ground Computer Development Laboratory activated (both in Bldg. 4708)
- 25 kW Power Module Project Office established within Program Development
- Space Station Platform Project Office established within Program Development (evolved from 25kW Power Module Project Office)
- 1st Productivity Enhancement Facilities constructed in Bldg. 4707

- President Reagan approved Space Station development
- Space Station Projects Office established
- Teleoperator and Robotics Evaluation Facility opened in Bldg. 4619
- Work began on Payload Operations Control Center facility in Bldg. 4663

- Huntsville population 142,500
- Port of Entry and U.S. Customs Office at Jetplex opened

- Alabama Space & Rocket Center Space Camp established
- 1st Panoply of the Arts Festival

- International Intermodal Facility construction began at Jetplex
- Foreign Trade Zone established

- Interstate spur I-565 construction began
- Joe Davis stadium opened; Huntsville Stars baseball team established

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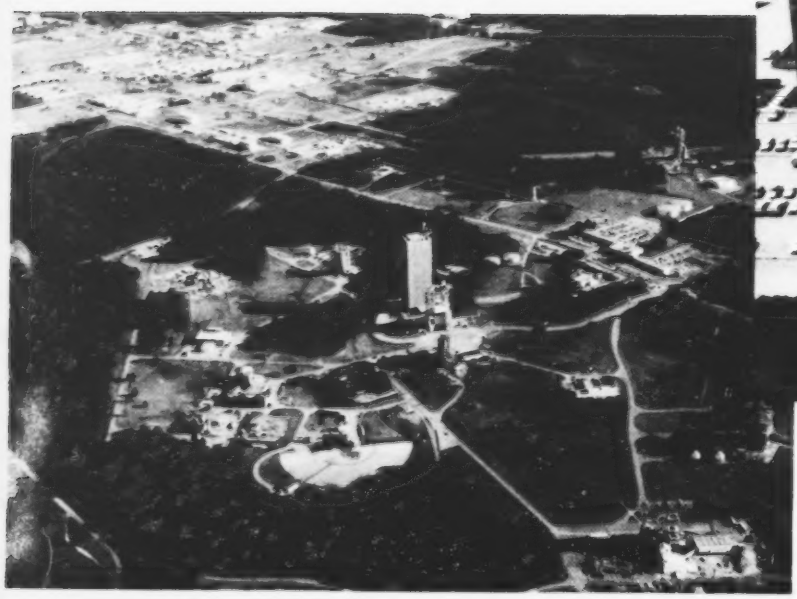
25 YEARS AT THE MARSHALL SPACE



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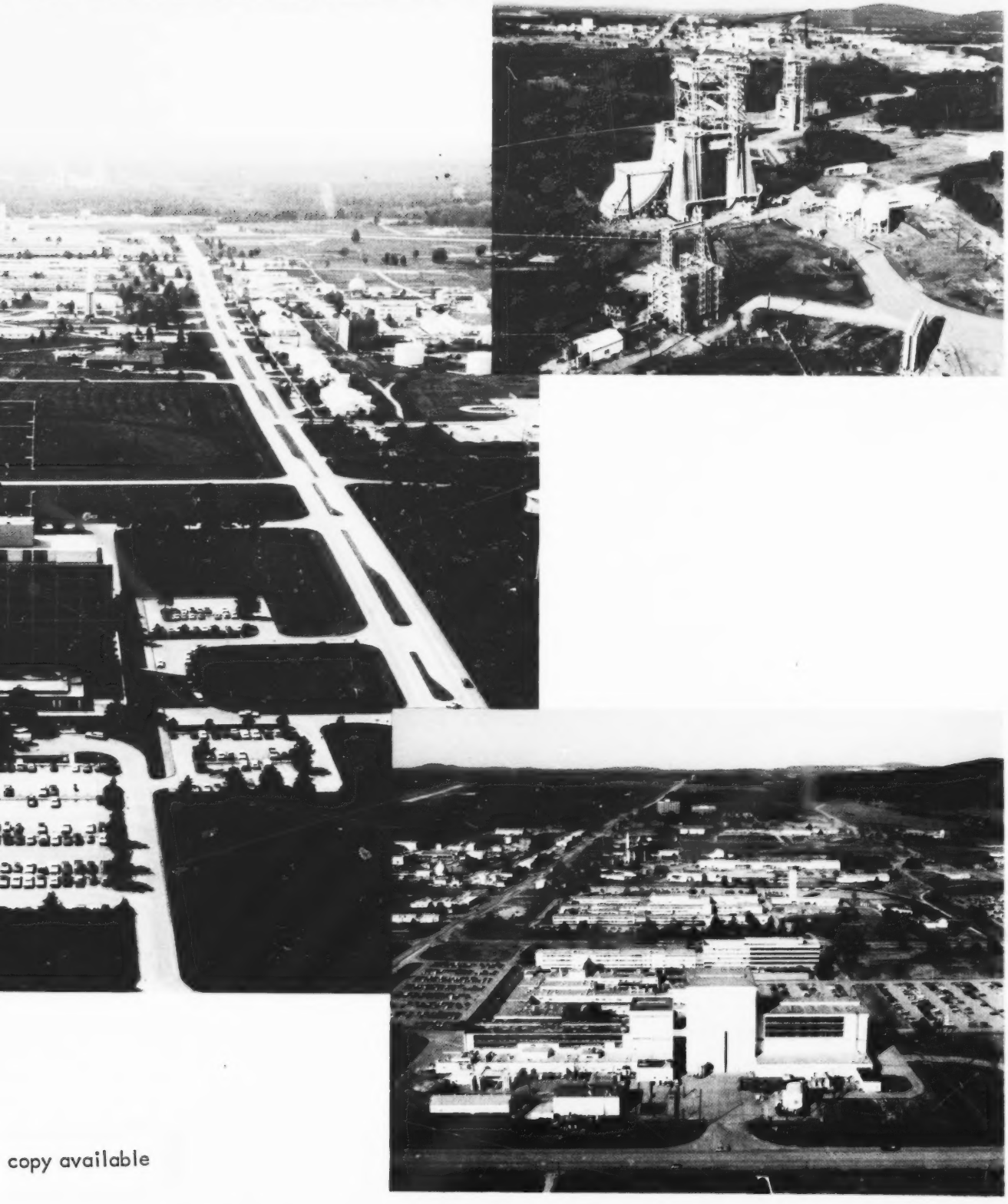
FLIGHT CENTER



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CHRONOLOGY

1960-1985

NASA
National Aeronautics and
Space Administration
Marshall Space Flight Center
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